N72-32650

NASA TECHNICAL MEMORANDUM

NASA TM X-2589

NASA TM X-2589

CASE FILE COPY

CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 THERMIONIC CONVERSION SPECIALIST CONFERENCES

by James F. Morris

Lewis Research Center
Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1972

1. Report No. NASA TM X-2589	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 THERMIONIC CONVERSION SPECIALIST CONFERENCES		5. Report Date September 1972
		6. Performing Organization Code
7. Author(s) James F. Morris		8. Performing Organization Report No. E-6989
		10. Work Unit No. 503-25
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report indexes and summarizes papers containing cesium-diode results from the proceedings of the 1963-to-1971 Thermionic Conversion Specialist Conferences. Lists of converter materials, geometries, conditions, outputs, and lifetimes accompany the references. Simple chemical designations for emitters, collectors, and additives direct the reader to appropriate selections.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Cesium diode performance Survey Nuclear engineering Nuclear thermionics	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	52	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 THERMIONIC CONVERSION SPECIALIST CONFERENCES

by James F. Morris

Lewis Research Center

SUMMARY

This report indexes and summarizes papers containing cesium-diode results from the proceedings of the 1963-to-1971 Thermionic Conversion Specialist Conferences. Lists of converter materials, geometries, conditions, outputs, and lifetimes accompany the references. Simple chemical designations for emitters, collectors, and additives direct the reader to appropriate selections.

INTRODUCTION

Most cesium-diode performance studies reach the Thermionic Conversion Specialist Conferences eventually. If the work fails to appear in the proceedings originally, it often enters in subsequent comparisons. And the accompanying references generally include expansive current, voltage data in agency, contractor, or company publications. So the Thermionic Conversion Specialist Conferences provide extensive cesium-diode output information. To increase the accessibility of this technology the present report indexes and summarizes such contributions for the past decade.

Beginning with the 1963 conference an annotated, chronological tabulation indicates 129 papers containing thermionic-converter results. Lists of diode materials, geometries, conditions, outputs, and lifetimes, if they were found, accompany the references. A simple chemical index for emitters, collectors, and additives directs the reader to appropriate selections. Because these chemical labels are guides not analyses, they lack the complexity of additive product permutations; they are easily recognized elemental or molecular forms. But they adequately identify the materials involved.

With a set of the proceedings for the Thermionic Conversion Specialist Conferences and the present report, comprehensive literature surveys on cesium-diode performances are readily available.

SIMPLE CHEMICAL INDEX FOR DIODE MATERIALS

Emitter	Reference
Cavity	53
Iridium (Ir)	10, 17, 18
Molybdenum (Mo)	5, 6, 7, 9, 10, 12, 14, 20, 21, 34, 38, 39, 47, 82, 84, 89, 92, 98, 100 (single-crystal 110 (1-xtal 110)), 120, 127,
Molybdenum-based alloy	98
Rhenium (Re)	3, 4, 12, 14, 15, 16, 19, 21, 22, 23, 27, 31 (electroetched), 40, 41, 42, 44, 56 (etched), 57 (etched), 58 (electro-etched), 59, 64, 65, 66, 67, 68, 69, 73, 74, 76, 79 (1-xtal 0001), 82, 87, 91, 95, 101, 103, 107 (etched), 114 (etched or 1-xtal 0001), 115 (chemically vapor-deposited (CVD)), 122 (etched), 125 (etched), 126
Ruthenium (Ru)	11, 45
Tantalum (Ta)	4, 5, 42, 46, 53, 66, 82
Tungsten (W)	2, 4, 8, 13, 14, 21, 22, 24, 25, 26, 28, 29, 30 (Cl^-CVD, 110), 33, 37, 43 (Cl^-CVD), 48 (F^-CVD (100) etched to 110), 49 (Cl^-CVD), 50 (Cl^-CVD, F^-CVD), 55 (VD), 60, 61, 62 (1-xtal 110), 63, 70 (Cl^-CVD, F^-CVD), 71 (Cl^-CVD), 72 (F^-CVD, four surface preparations), 80 (F^-CVD etched to 110), 81 (1-xtal 110), 82 (several orientations and surface preparations), 83 (1-xtal 110), 84 (F^-CVD), 85 (F^-CVD), 86 (Cl^-CVD), 88 (F^-CVD), 90 (F^-CVD), 90 (F^-CVD, four surface preparations), 93 (SIMCON), 94 (Cl^-CVD), 96 (CVD), 97 (physically vapor-deposited (PVD)), 102 (1-xtal 110, Cl^-CVD, F^-CVD), 104 (1-xtal 110, Cl^-CVD, F^-CVD), 105 (1-xtal 110, Cl^-CVD, F^-CVD), 106 (F^-CVD etched to 110, Cl^-CVD, F^-CVD), 108 (Cl^-CVD), 109 (Cl^-CVD, F^-CVD), 110, 111, 112, 113 (F^-CVD), 116 (CVD), 117 (Cl^-CVD), 118 (F^-CVD), 121 (Cl^- vapor deposited by thermal decomposition (TVD)), 122 (PVD, Cl^-CVD), 123 (Cl^-CVD), 124 (PVD, Cl^-CVD, F^-CVD), 126, 128 (CVD), 129 (Cl^-CVD, SIMCON)

Emitter	Reference
Tungsten-based mixture	98 ("tungsten-based alloy," "tungsten, rhenium"), 32 (W, 20 percent Re), 78 (W, 25 percent Re), 82 (W, 25 percent Re), 1 (with a small amount of Th), 119 (W, 2 percent ThO_2)

Collector	Reference
Grooved	36
Inconel	8
Molybdenum (Mo)	3, 4, 5, 11, 12, 13, 15, 19, 22, 24, 27, 30, 31, 33, 34, 36 (with and without grooves), 38, 39, 40, 41, 42, 44, 45, 49, 50, 51, 53, 56, 57 (VD), 59, 62, 63, 64, 69, 71, 74, 76, 82, 84, 89, 91, 92, 93 (SIMCON), 94, 95, 96, 99, 100 (1-xtal 110), 104, 105 (polycrystal (polyxtal) or PVD (110)), 108 (PVD), 110, 113, 114, 116, 118, 120, 122, 123 (PVD), 124 (PVD), 125 (PVD), 128
Nickel (Ni)	2, 7, 9, 10, 14, 16, 20, 21, 25, 28, 29, 33, 37, 43, 46, 51, 60, 82, 121
Niobium (Nb)	6, 21, 29, 45, 47, 48, 50, 56, 58, 66, 67, 68, 69, 70, 72, 79, 80, 81, 82, 85, 86, 90, 97, 98, 99, 101, 102, 103, 104, 105, 106, 107, 109, 112, 117, 121, 122, 123, 126, 129
Niobium-based mixtures	45 (Nb, 0), 55 (Nb, 1 percent Zr), 84 (Nb, 1 percent Zr), 88 (Nb, 1 percent Zr), 115 (Nb, 1 percent Zr), 127 (Nb, 1 percent Zr)
Palladium (Pd)	58
Rhenium (Re)	40, 45, 58, 65, 82, 87 (Cl^-CVD), 91
Ruthenium (Ru)	11, 45
Silver (Ag)	23
Stainless steel	1, 17, 18 (304)
Tantalum (Ta)	4, 5, 26, 111
Tungsten (W)	25 (from emitter on Ni collector), 61, 83 (1-xtal 110), 121, 123 (1-xtal 110, polycrystalline)
Tungsten-based mixtures	78 (W, 25 percent Re), 82 (W + WO_2 on Nb collector)

Additive	Reference
Argon (Ar)	35, 46, 75
Barium (Ba)	13, 111, 120
Carbon (C) (possible diffusion into diode from UC)	3, 6, 117
Cesium fluoride (CsF)	12, 24, 34
Cesium oxide (Cs_2O)	44, 52
Fluorine (F or F_2)	12, 24, 34
Hydrogen (H or H_2)	2, 14
Iodine (I or I_2)	46
Krypton (Kr)	46, 54
Nitrogen (N or N_2) (possible diffusion into diode from UN)	126
Oxygen (O or O_2)	7 (possible diffusion into diode from UO_2), 8 (UO_2), 9 (UO_2), 23, 28 (UO_2), 44, 45 (in Nb), 47 (UO_2), 52, 55 (UO_2), 88 (UO_2), 89 (UO_2), 104, 105, 112 (UO_2), 114, 117 (UO_2), 119 (from ThO_2 in emitter), 124, 125 (UO_2)
Thorium (Th) (from the emitter composition)	1 (in W), 119 (W, 2 percent ThO_2)
Uranium (U) (possible diffusion into diodes from fuel)	3, 6, 7, 8, 9, 28, 47, 55, 88, 89, 112, 117, 125, 126
Xenon (Xe)	17, 18, 46, 54, 75

Emitter (E), Collector (C), Combination	Reference
Iridium (E)	
Stainless steel (C)	17, 18
Molybdenum (E)	
Molybdenum (C)	5, 12, 34, 38, 39, 82, 89, 92, 100, 120
Niobium, 1 percent zirconium (C)	127
Niobium (C)	6, 47, 98
Nickel (C)	7, 9, 10, 14, 20

Emitter (E), Collector (C), Combination	Reference
Molybdenum-based alloy (E)	
Niobium (C)	98
Rhenium (E)	
Molybdenum (C)	3, 4, 12, 15, 19, 22, 27, 31, 40, 41, 42, 44, 56, 57, 59, 64, 69, 74, 76, 82, 91, 95, 114, 122, 125
Nickel (C)	14, 16, 82
Niobium (C)	21, 56, 58, 66, 67, 68, 69, 79, 82, 101, 103, 107, 122, 126
Niobium, 1 percent zirconium	115
Palladium (C)	58
Rhenium (C)	40, 58, 65, 82, 87, 91
Silver (C)	23
Tantalum (C)	4
Ruthenium (E)	
Molybdenum (C)	11, 45
Niobium (C)	45
Niobium with oxygen (C)	45
Rhenium (C)	45
Ruthenium (C)	11, 45
Tantalum (E)	
Molybdenum (C)	4, 5, 42
Nickel (C)	46
Niobium (C)	66, 82
Tantalum (C)	4, 5
Tungsten (E)	
Inconel (C)	8
Molybdenum (C)	13, 22, 24, 30, 33, 49, 50, 62, 63, 71, 82, 84, 93, 94, 96, 104, 105, 108, 110, 113, 116, 118, 123, 124, 128
Nickel (C)	2, 14, 21, 25, 28, 29, 33, 37, 43, 60, 82, 121
Niobium (C)	21, 29, 48, 50, 70, 72, 80, 81, 82, 85, 86, 90, 97, 102, 104, 105, 106, 109, 112, 117, 121, 122, 123, 126, 129
Niobium, 1 percent zirconium (C)	55, 84, 88
Tantalum (C)	4, 26, 111

Emitter (E), Collector (C), Combination	Reference
Tungsten (C)	25, 61, 83, 121, 123
Tungsten and tungsten oxide on a niobium collector (C)	82
"Tungsten-based alloy" (E)	
Niobium (C)	98
Tungsten, rhenium alloys (E)	
Nickel (C)	82
Niobium (C)	98
Tungsten, 25 percent rhenium (C)	78
Tungsten with a small amount of thorium (E)	
Stainless steel (C)	1

CHRONOLOGICALLY ORDERED, ANNOTATED REFERENCES ON CESIUM-DIODE PERFORMANCES FROM THE 1963-TO-1971 PROCEEDINGS OF THE THERMIONIC SPECIALIST CONFERENCES

Report on the Thermionic Conversion Specialist Conference. IEEE, 1963.

1. Houston, John M.: Measurements of Emitter Heat Balance in a Cesium Thermionic Converter, pp. 214-223.

Emitter	W with a small amount of Th; T_E = 1900 to 2200 K
Collector	stainless steel; T_C = 583 to 783 K and optimum
Cesium gap	1 mm; T_R = 424 to 573 K
Additive	Th
Geometry	cylindric, 1.52-cm diameter, 13.3 cm^2
Output	0.4 to 0.8 W/cm^2 with 1.2 to 2.4 percent efficiency at 1900 K; 6 to 9 W/cm^2 with 8.8 to 12 percent efficiency at 2200 K

2. Rump, B. S.; Bryant, J. F.; and Gehman, B. L.: Study of the Influence of Additives on Work Function and Power Output of Thermionic Cells, pp. 236-239.

Emitter	W; T_E = 1000 to 2300 K
Collector	Ni; T_C = 400 to 1000 K and optimum
Cesium gap	T_R = 100° and 200° C
Additive	H_2
Geometry	filamentary
Output	power for Cs alone above that for Cs + H_2 with T_R = 100° C; for T_R = 200° C power for Cs + H_2 above that for Cs alone at T_E < 1900 K; for T_R = 200° C power for Cs + H_2 at 1500 K equal to that for Cs alone at 2100 K; power range 10^{-6} to 10^{-1} W/cm^2

3. Howard, Robert C.; Keller, D. L.; and Smith, C. K.: Converter Performance Test of a Rhenium Emitter in Contact with a Carbide Fuel, pp. 287-294.

Emitter	Re (UC backed); T_E = 1550° C (129 hr), 1600° C (72 hr)
Collector	Mo; T_C = 603° to 617° C
Additive	U and C possible
Geometry	plane
Output	5 W/cm^2 (0.5 V, 1550° C), more than 8 W/cm^2 (0.5 V, 1600° C), no degradation of performance
Lifetime	201 hr; thermal bond separation in fuel, emitter sandwich

4. Merra, S. G.; and Weinstein, J. H.: Recent Progress in the Development of Solar Thermionic Converters, pp. 295-304.

Emitter	Re, Ta, or W; T_E = 1980 to 2050 K
Collector	Mo or Ta; radiation cooled
Cesium gap	0.051 to 0.064 mm; T_R optimized
Geometry	plane solar diodes
Output	as shown in the following table (from ref. 4):

SOLAR HARDWARE CONVERTERS (1962-1963)

Type	Date	Emitter	Collector	Emitter area, cm^2	Spacing, mm	Volts	Amperes	Watts	Emitter temperature, K	Geometry	Number built
Series VI	1962-1963	Ta	Ta	2	0.064	0.8 1.0	28.0 18.7	22.4 18.7	2000 2000	Flat	21
VI-S-15	1962	Ta	Ta	2	0.064	0.6	71.0	42.6	2050	Flat	
EX-1, -7	1962	Re	Mo	2	0.058	0.7 1.0	50.0 13.2	35.0 13.2	1990 2040	Flat	2
EX-2, -3	1962	Re	Ta	2	0.058	0.7	30.0	21.0	1990	Flat	2
EX-4, -5, -6	1962	W	Ta	2	0.058	0.5 1.0	27.0 6.8	13.5 6.8	1980 1980	Flat	
EX-8	1962	Ta	Mo	2	0.064	0.7 1.0	25.5 11.0	19.0 11.0	2000 2000	Flat	1
EX-9	1962	Ta	Ta	2	0.064	0.6 1.0	40.0 12.0	24.0 12.0	2000 2000	Flat	1
Series VII	1963	Ta	Ta	2	0.051	0.5 1.0	40.0 12.0	20.0 12.0	2000 2000	Flat	9
Series 2	1962	Ta	Mo	3	0.051	1.0	20.0	20.0	2000	Flat	11
Series 300	1963	Ta	Mo	3	0.051	0.5	58.0	29.0	2000	Flat	5

Lifetime over 2000 hr

5. Rouklove, P.: Results of Laboratory Tests of Set Thermionic Converters and Generators, pp. 305-313.

Emitter Mo (C), Ta (A, B, D); $T_E = 1677^\circ$ C (D) and 1700° C (A, B, C)
Collector Mo (B, C, D), Ta (A); radiation cooled
Cesium gap 0.051 mm (A), 0.025 to 0.203 mm (B), 0.127 mm (B); T_R optimized
Geometry plane solar diodes
Output 11 to 18 W/cm^2 to 0.6 V with 8.5 to 9 percent efficiency (A), 5 to 8.5 W/cm^2 maximums for 0.076 to 0.025 mm at 0.6 V with 5.4 percent efficiency (B), 9.3 W/cm^2 maximum with 7.4 percent efficiency (B), 7.0 to 8.5 W/cm^2 (C), 10 to 13 W/cm^2 (D)
Lifetime some in excess of 2000 hr

6. Busse, C. A.; Caron, R.; and Salmi, Ernest W.: In-Pile Test of a Thermionic Converter, pp. 314-322.

Emitter	Mo ((UZr)C backed)
Collector	Nb
Cesium gap	0.5 mm
Additive	U and C (through the emitter and through a hole in the emitter)
Geometry	cylindric with emitter cavity, diode gap, and Cs reservoir interconnected
Output	0.22 W/cm^2 at 1 MW reactor power ($T_R = 177^\circ$ C)
Lifetime	cesium heater failed in initial checkouts and allowed no high-power runs in the reactor

7. Block, Fred G.; Eastman, G. Y.; and Harbaugh, Willis E.: The Design, Development, and In-Pile Testing of a Nuclear-Fueled Thermionic Energy Converter, pp. 323-331.

Emitter	Mo (UO_2 backed); $T_E = 1200^\circ$ to 1700° C with 1350° C design optimum
Collector	Ni; T_C optimums 525° to 825° C (for 1200° to 1700° C); 570° C for $T_E = 1350^\circ$ C
Cesium gap	0.838 to 0.076 mm optimums (for 1200° to 1700° C), 0.279 mm for $T_E = 1350^\circ$ C; T_R optimums 270° to 380° C (for 1200° to 1700° C), 310° C for $T_E = 1350^\circ$ C
Additive	U and O possible
Geometry	cylindric; 60 cm^2
Output	1.3 to 15 W/cm^2 (for 1200° to 1700° C), 3.2 W/cm^2 at $T_E = 1350^\circ$ C; 11 percent "typical efficiency"; in-pile 2.25 W/cm^2 at 9 percent efficiency (see ref. 9)
Lifetime	2600 hr for one and 1400 hr at 3 W/cm^2 for another out of pile, both continuing; in-pile performance plummeted after 300 hr

8. Beckjord, Eric S.: Test Results on an In-Pile Nuclear Thermionic Converter, pp. 332-340.

Emitter	W (UO_2 backed); $T_E = 1700^\circ$, 1720°, 1800° C
Collector	Inconel; $T_C = 650^\circ$ to 700° C
Cesium gap	0.254 mm; $T_R = 335^\circ$ to 345° C for power maximums
Additive	U and O possible
Geometry	cylindric; 1.17-cm diameter, 8.6 cm^2
Output	4 W/cm^2 at 0.6 V and 1700° C, 5 W/cm^2 at 0.64 V and 1720° C, 6 W/cm^2 at 0.78 V and 1800° C; 10.5 percent efficiency at peak 6.2 W/cm^2 and 1800° C
Lifetime	224 hr in testing reactor before Cu pinchoff failed

9. Eastman, G. Y.; Basiulis, A.; and Harbaugh, W. E.: Thermionic Converter Operation in Multiple Connection, pp. 348-355.

Emitter	Mo (UO_2 back); $T_E = 1300^\circ$ to 1500° C
Collector	Ni; T_C optimized
Cesium gap	optimized widths and T_R's
Geometry	cylindric, 60 cm^2
Output	1 to 4 W/cm^2 at 8 to 12 percent efficiencies (see ref. 7); complete performance map

10. Martini, W. R.: Internal Flame-Heated Thermionic Converters, pp. 356-361.

Emitter	Ir at 1430° C, Mo at 1400° C
Collector	Ni
Cesium gap	0.762 mm with $T_R = 252^\circ$ C for Ir, 0.208 mm with $T_R = 315^\circ$ C for Mo
Geometry	plane; 2.54-cm diameter
Output	projected from RCA tube 1195A data, 5.5 W/cm^2 for Ir, 4.25 W/cm^2 for Mo

Report on the Thermionic Conversion Specialist Conference. IEEE, 1964.

11. Kennedy, A. J.; and Trimmer, D. S.: The Performance of Ruthenium as an Electrode in a Thermionic Converter, pp. 63-70.

Emitter	two of hot-pressed Ru, one of plasma-sprayed Ru; T_E = 1500 to 1900 K
Collector	one of arc-cast Mo, two of plasma-sprayed Ru; T_C = 698 to 1031 K
Cesium gap	0.102 to 0.762 mm; T_R = 535 to 589 K
Geometry	plane
Output	8 W/cm^2 for 0.254 mm and T_E = 1800 K; Ru gives higher power densities than Re and Ir produce for gaps wider than 0.254 mm

12. Jester, Alfred A.: The Influence of a Cesium Fluoride Additive on the Power Output of Cesium Diodes with Molybdenum and Rhenium Emitters, pp. 93-99.

Emitter	(1) Mo or (2) Re; T_E = 1800 K (A), 1900 K (B), 2000 K (C)
Collector	Mo; T_C = 750 or 800 K or optimum
Cesium gap	0.05 to 0.4 mm; T_R = 531 to 609 K or optimum
Additive	CsF at T_{CsF} = 800 K
Geometry	plane

Output	for Cs with CsF: emitter (1A) 12 W/cm^2 at 0.35 V; (1B) 20 W/cm^2 at 0.5 V; (1C) 24 W/cm^2 at 0.6 V; (2A) 16 W/cm^2 at 0.4 V; (2B) 20 W/cm^2 at 0.65 V; (2C) 28 W/cm^2 at 0.7 V; at identical voltages Cs with CsF gave more power, allowed lower Cs pressure, or permitted greater gap widths; good performance maps

13. Psarouthakis, John: Thermionic Energy Converter with Barium and Cesium Vapors, pp. 100-109.

Emitter	W; T_E = 1700, 1800, 1900, or 2000 K
Collector	Mo; T_C's within 25° C above T_{Ba}'s
Cesium gap	0.025 to 1.016 mm; T_R = 425 to 647 K
Additive	Ba; T_{Ba} = 1000 to 1200 K
Geometry	plane
Output	8.5 W/cm^2 at T_E = 2000 K, T_C = 1100 K, T_{Ba} = 1080 K, T_{Cs} = 470 K with a "fundamental conversion efficiency" of 27 percent; output dropped from 8.5 to 8.2 W/cm^2 as the gap widened from 0.051 to 1.016 mm

14. Hall, W. B.; and Shoemaker, R. E.: Control of Gas Impurities in a Thermionic Converter, pp. 110-114.

Emitter	Mo, Re, or "special" W; T_E = 1250° to 1550° C
Collector	Ni; optimum T_C's
Cesium gap	optimum width; optimum T_R's
Additive	H_2
Geometry	plane; 11.7 cm^2
Output	at 1550° C, 9.5 W/cm^2 (Mo), 12 W/cm^2 (Re), 17 W/cm^2 (W); H_2 from 10^{-6} to 10^{-3} torr did not affect W or Re; it dropped Mo performance 15 percent and lowered the output of a contaminated W emitter over 40 percent.

15. Shavit, Arthur; and Hatsopoulos, George N.: Operation of a Thermionic Converter for the Ion-Rich Unignited Mode, pp. 206-213.

Emitter	Re; T_E = 1520 to 1900 K
Collector	Mo
Cesium map	0.008 to 0.254 mm; T_R = 480 to 539 K
Geometry	plane, guarded
Output	very low (unignited mode)

16. Wilson, V. C.: Evidence for a Double Sheath Adjacent to the Emitter, pp. 285-290.

Emitter	Re; T_E = 1700 to 2123 K
Collector	Ni; T_C = 873 K
Cesium gap	0.051 mm; T_R = 593 to 643 K
Output	38 W/cm^2 at 0.5 V and 2000 K

17. Kaplan, C.: Pulsed-Discharge Experiments in a Thermionic Converter, pp. 326-332.

Emitter	Ir; $T_E = 1370^\circ$ C
Collector	stainless steel; $T_C = 290^\circ$ to 760° C
Cesium gap	0.310 mm; $T_R = 290^\circ$ C
Additive	Xe; 60 torr
Geometry	plane
Output	postulate of higher performance with Xe because of increased Cs_2^+ decay times

18. Kaplan, C.; and Merzenich, J. B.: Xenon Addition Experiment in a Thermionic Converter, pp. 333-344.

Emitter	Ir; $T_E = 1260^\circ$ to 1370° C
Collector	304 stainless steel; $T_C = 607^\circ$ to 682° C and 1.62 T_R
Cesium gap	0.178 to 0.762 mm; $T_R = 270^\circ$ to 310° C
Additive	Xe; 60 torr
Geometry	plane
Output	8.3 W/cm^2 maximum for Cs + Xe with $T_E = 1370^\circ$ C; Xe increased output 15 to 80 percent; Ne decreased output; performance curves

19. Merra, S.: Test Results of Solar Thermionic Converters Using Rhenium Emitters, pp. 350-359.

Emitter	Re pyrolytic or pressure-bonded, $T_E = 2000^\circ$ C
Collector	Mo, $T_C = 529^\circ$ to 821° C
Cesium gap	0.051 mm, $T_R = 336^\circ$ to 398° C
Geometry	plane solar diode, 2.0 cm^2
Output	as shown in the following table (from ref. 19):

Performance of Series VIII Prototypes at 2000 K

Diode	I, A	J, A/cm^2	V, volts	Output power, W	T_R, ^oC	T_C, ^oC	Input power, W	Efficiency, η	Diode weight, g
VIII-P-1 -	15.4	7.7	1.0	15.4	362	652	---	------	230
good quality	30.0	15.0	.85	25.5	369	652	---	------	
pyrolytic	39.0	19.5	.8	31.2	388	652	---	------	
rhenium	60.0	30.0	.688	41.4	384	652	---	------	
emitter	80.7	40.35	.6	48.4	398	652	---	------	
VIII-P-2a -	24.0	12.0	1.0	24.0	349	529	300	0.08	494
pressure-	34.0	17.0	.9	30.6	347	561	325	.0942	
bonded	47.5	23.75	.8	38.0	357	616	358	.106	
rhenium	61.0	30.5	.7	42.7	372	666	388	.110	
emitter	78.0	39.0	.6	46.8	382	733	450	.104	
VIII-P-2b -	12.6	6.3	1.0	12.6	336	543	263	0.0479	494
pyrolytic	16.0	8.0	.9	14.4	338	554	270	.0534	
rhenium	24.0	12.0	.8	19.2	348	584	292	.0658	
emitter with	32.0	16.0	.7	22.4	355	623	310	.0724	
impurities	47.0	23.5	.6	28.2	376	702	350	.0806	
VIII-P-3 -	29.0	14.5	1.0	29.0	353	661	310	0.0936	255
pressure-	39.0	19.5	.9	35.1	360	698	335	.1048	
bonded	49.0	24.5	.8	39.2	366	751	365	.1073	
rhenium	58.0	29.0	.7	40.6	380	793	385	.1053	
emitter	65.0	32.5	.6	39.0	387	821	400	.0975	

20. Harbaugh, W. E.; Buzzard, R. J.; and Basiulis, A.: The Design and Evaluation of a 400-Watt Thermionic Converter, pp. 360-368.

Emitter	Mo apparently; $T_E = 1450^o$ to 1800^o C
Collector	Ni apparently; $T_C = 610^o$ to 740^o C
Cesium gap	$T_R = 335^o$ to 345^o C
Geometry	cylindric; 40 cm^2
Output	up to 13.75 W/cm^2; efficiencies as high as 19.8 percent; good performance maps
Lifetime	2600 hr average for 12 diodes
Comment	according to RCA, A-1272 is a high-performance version of A-1197A (Mo, Ni)

21. Wilson, V. C.: Rapporteur Paper on "Converter Performance" from The International Conference on Thermionic Electrical Power Generation, London, England, pp. 258-265.

Emitter	(1) W, (2) Mo, (3) W, (4) Re, (5) W; T_E = (1) 2263 K, (2) 1973 K, (3) 1900 and 2000 K, (4) 1900 K, (5) 2100 K
Collector	(1) Ni, (2) unknown, (3) Nb, (4) Nb, (5) Nb; T_C = 898 to 1053 K for (1)
Cesium gap	(1) 0.051, (2) 0.3, (3) 0.16, (4) 0.25, (5) 0.25 mm; T_R = 593 to 693 K for (1)
Geometry	(1) plane, the rest cylindric
Output	(1) over 75 W/cm^2, (2) 4.2 W/cm^2, (3) 5 to 8.4 W/cm^2, (4) 3.75 W/cm^2, (5) 10 W/cm^2; efficiency of (2) 8 percent, (3) 11 percent; performance map for (1)

22. van Someren, L.; Lieb, D.; and Kitrilakis, S. S.: Evaluation of Thermionic Emitter Surfaces, pp. 266-275.

Emitter	Re (four surface preparations), W; T_E = 1605 to 1975 K for Re, 1630 to 1950 for W
Collector	Mo; T_C = optimum
Cesium gap	optimum; T_R = optimum
Geometry	plane; 3-cm^2 emitter, 2-cm^2 collector, guard
Output	22 W/cm^2 for Re and 14 for W at T_E = 1850 K; 40 W/cm^2 for Re at 1975 K; fully optimized performance plots

23. Levine, J. D.; Harbaugh, W. E.; and Shoemaker, R. E.: Oxygen as a Controllable, Reversible, and Beneficial Additive in the Cesium Converter, pp. 276-280.

Emitter	Re; T_E = 1350° C
Collector	Ag; T_C = 350° to 550° C
Cesium gap	0.356 mm; T_R = 285° and 290° C
Additive	O_2 introduced through Ag membrane on collector
Geometry	plane
Output	4.6 W/cm^2 with 11.6 percent efficiency at 0.2 V, T_C = 400° C, and T_R = 285° C; performance plots

24. Lieb, D.: Performance of Tungsten-Emitter Thermionic Converter in the Presence of Cesium Fluoride Additive, pp. 281-288.

Emitter	W; T_E = 1630 to 1950 K

Collector	Mo; T_C = 813 to 943 K
Cesium gap	0.025 to 0.762 mm; T_R = 480 to 645 K
Additive	CsF; T_{CsF} = 378 to 770 K
Geometry	plane, guarded
Output	40 W/cm^2 at 0.58 V for Cs + CsF, T_E = 1870 K, T_C = 893 to 943 K, T_{CsF} = 623 K, T_R = 538 to 609 K, d = 0.127 mm; 9 W/cm^2 at 0.58 V for Cs alone, T_E = 1850 K, T_C = 862 K, T_R = 562 to 635 K, d = 0.153 mm; good performance plots

25. Lawrence, J.; and Perdew, J. P.: Effect on Thermionic Converter Performance of Emitter Material Evaporated on a Low Work Function Collector, pp. 289-296.

Emitter	W; T_E = 1633 to 2183 K
Collector	Ni or W (from emitter) on Ni; T_C = 863 to 973 K
Cesium gap	0.051 mm; T_R = 553 to 663 K
Geometry	plane, guarded
Output	at 100 A/cm^2, 78 W/cm^2 (2183 K), 65 W/cm^2 (2074 K), 47 W/cm^2 (1963 K), and 35 W/cm^2 (1855 K) for Ni and 20 W/cm^2 (1855 K) for W on Ni; subsequent contamination nearly regenerated the initial performance; good I, V curves

26. Blue, E.; and Ingold, J. H.: The Effect of High Collector Temperature on the Power Output and Efficiency of a Thermionic Converter: Experimental, pp. 297-305.

Emitter	W; T_E = 2150 or 2225 K
Collector	Ta; T_C = 1355 to 1675 K
Cesium gap	0.051 to 0.432 mm; T_R = 633 to 693 K and optimum
Geometry	plane, guarded
Output	at T_E = 2225 K, T_C = 1500 K, T_{Cs} = 673 K, d = 0.135 mm, 27.5 W/cm^2 maximum for 0.45 V and 9 percent efficiency and 10.5 percent maximum efficiency; extensive performance plots show effects of high collector temperatures

27. Kitrilakis, S.; and Brosens, P.: Experimental Correlation of Electron Emission Cooling and Optimum Collector Temperature, pp. 316-324.

Emitter	Re; T_E = 1680 to 2000 K
Collector	Mo; T_C = 873 to 1073 K
Cesium gap	0.013 to 0.508 mm; T_R = 543 to 630 K
Geometry	plane, guarded

Output 5.3 W/cm^2 at 0.38 V, T_E = 1740 K, T_C = 1053 K, T_R = 588 K, d = 0.102 mm; I, V plots; an attempt to correlate optimum collector temperatures

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1966.

28. Gilliland, D. L.: Performance and Life Test of a Cylindrical Thermionic Converter, pp. 1-5.

Emitter	W (UO_2 backed); T_E = 1500° to 1830° C
Collector	Ni; T_C = 700° C
Cesium gap	0.127 mm; T_R = 330° to 370° C
Additive	U and O possible
Geometry	cylindric; 1-cm diameter, 8.6 cm^2
Output	18.8 W/cm^2 maximum measured for T_E = 1830° C; 10.2 W/cm^2 and 15.8 percent efficiency during life test at T_E = 1730° C, T_C = 700° C, and T_R = 345° C
Lifetime	9227 hr before shorting out

29. Lawrence, J.; and Wilson, V. C.: A Comparison of Niobium and Nickel as Thermionic Converter Collector Materials, pp. 6-11.

Emitter	W; T_E = 1673 to 2153 K
Collector	Nb or Ni; T_C = 873 to 1173 K
Cesium gap	0.025 to 0.508 mm; T_R = 583 to 683 K
Geometry	plane
Output	voltage is 0.1 to 0.16 V higher with Ni rather than Nb; good performance curves

30. Hobbs, R. L.; and Psarouthakis, J.: A Converter with Vapor Deposited Tungsten Emitter, pp. 12-18.

Emitter	Cl^-CVD (~110) W; T_E = 1900 to 2000 K
Collector	Mo; T_C = 833 to 1033 K
Cesium gap	0.203 mm; T_R = 563 to 588 K
Geometry	plane
Output	11 W/cm^2 with 0.5 V at T_E = 2000 K; 9 W/cm^2 with 0.45 V at T_E = 1900 K

31. Kitrilakis, S. S.; and Rufeh, F.: The Output Characteristics of an Electroetched Rhenium Surface, pp. 19-26.

Emitter	Electroetched Re; T_E = 1555 to 1960 K

Collector	Mo; T_C = 843 to 943 K and optimum
Cesium gap	0.013 to 1.016 mm and optimum; T_R = 514 and 616 K and optimum
Geometry	plane, guarded
Output	fully optimized, 3 W/cm^2 with 0.2 V at T_E = 1560 K, 7.5 W/cm^2 with 0.3 V at T_E = 1650 K, 13 W/cm^2 with 0.5 V at T_E = 1740 K, 18 W/cm^2 with 0.7 V at T_E = 1860 K, and 40 W/cm^2 with 0.8 V at T_E = 1960 K; electroetched Re is considerably more effective than electropolished Re

32. Case, J. M.: An Investigation of Thermionic Converter Dynamic Operation, pp. 47-56.

Emitter	W, 20 percent Re; T_E = 1500^o to 1800^o C
Geometry	cylindric
Output	little information to define performance given in this dynamics study; influences of T_C and T_R considered negligible

33. Sutherland, C. D.; and Ranken, W. A.: Optimization of a Thermionic Diode, pp. 57-65.

Emitter	W; T_E = 2100 K maximum
Collector	Mo or Ni; T_C = 1000 K
Cesium gap	0.127 or 0.178 mm; T_R = 598 or 643 K
Geometry	cylindric; 1.2-cm diameter, variable length (for the analysis)
Output	previous data used as bases for numerical optimizations with respect to emitter length and support and output voltage

34. Cahen, O.; and Defranould, P.: Resultats Experimentaux Obtenus Sur des Convertisseurs du Type Nucléaire à Cesium et Fluorure de Césium, pp. 66-69.

Emitter	Mo; T_E = 1450^o and 1700^o C
Collector	Mo; T_C optimum
Cesium gap	0.25 mm; T_R optimum
Additive	CsF; T_{CsF} = 325^o to 550^o C
Output	at 2 W/cm^2 6.7 percent efficiency for Cs and 8 percent for Cs + CsF; at 4 W/cm^2 9.7 percent efficiency for Cs and 10 percent for Cs + CsF; at 6 W/cm^2 11.7 percent efficiency for Cs and 10.9 percent for Cs + CsF

35. Rufeh, F.; and Kitrilakis, S. S.: Thermionic Converter Performance in Presence of Inert Gases, pp. 91-98.

Emitter	T_E = 1863, 1740, 1645 K

Collector	T_C = 873 K
Cesium gap	0.051, 0.254, 0.508 mm; T_R = 558 to 638 K
Additive	0 to 100 torr
Geometry	plane, guarded
Output	increasing Ar pressure decreases diode output; 10 torr of Ar attenuates electron current 5 to 15 percent

36. Rufeh, F.: The Volt-Ampere Characteristics of a Grooved-Collector Thermionic Diode, pp. 99-105.

Emitter	T_E = 1625, 1645 K
Collector	Mo with and without grooves; T_C = 773, 873 K
Cesium gap	0.025 to 0.635 mm; T_R = 553 K, 593 K, and variable
Geometry	plane, guarded
Output	small increase in output for grooved collector over flat one even without optimization

37. Lazaridis, L. J.; and Pantazelos, P. G.: Design of a 5-Kilowatt Flame-Heated Thermionic Power Supply, pp. 126-132.

Emitter	W; $T_E = 1400^\circ$ C
Collector	Ni
Cesium gap	0.254 mm
Geometry	20 cm^2
Output	5 W/cm^2 at 0.55 V and 10 percent efficiency

38. Harbaugh, W. E.; and Longsderff, R. W.: The Development of an Insulated Thermionic-Converter/Heat-Pipe Assembly, pp. 139-143.

Emitter	Mo; $T_E = 1300^\circ$ to 1500° C
Collector	Mo; $T_C = 625^\circ$ to 675° C
Cesium gap	$T_R = 265^\circ$ to 325° C
Geometry	cylindric, 40 cm^2
Output	2.05 W/cm^2 (0.25 V), 2.8 W/cm^2 (0.28 V), 4.0 W/cm^2 (0.32 V), 5.0 W/cm^2 (0.38 V), 6.9 W/cm^2 (0.45 V)

39. Shefsiek, P. K.: Thermal Measurements of a Thermionic-Converter/Heat-Pipe System, pp. 169-174.

Emitter	Mo; $T_E = 1450^\circ$ to 1530° C
Collector	Mo; $T_C = 475^\circ$ to 710° C
Cesium gap	$T_R = 95^\circ$ to 321° C
Geometry	cylindric; 50 cm^2
Output	3.2 W/cm^2 at 0.6 V, $T_E = 1510^\circ$ C, $T_C = 710^\circ$ C, $T_R = 318^\circ$ C

40. Campbell, A. E.; and Jensen, A. O.: Performance of Prototype Thermionic Converters, pp. 175-184.

Emitter	Re; $T_E = 1735^\circ$ C
Collector	Re or Mo; $T_C = 507^\circ$ to 790° C
Cesium gap	0.089 mm (Re, Re), 0.0051 mm (Re, Re), 0.089 mm (Re, Mo)
Geometry	plane; 2.0 cm^2 faces, 0.4 cm^2 sidewalls
Output	20 W/cm^2 at 0.8 V for Re, Re diode with 0.051-mm gap; 15.2 W/cm^2 at 0.8 V, 21.0 W/cm^2 at 0.7 V, 26.4 W/cm^2 at 0.6 V for Re, Re diode with 0.089-mm gap; Re collector gave average of 0.08 V more than its Mo counterpart

41. Rouklove, P.: Thermionic Converter and Generator Tests, pp. 185-191.

Emitter	Re; $T_E = 1600^\circ$, 1700°, 1800° C
Collector	Mo; radiation cooled (T_C near optimum)
Cesium gap	0.038 mm; T_R optimum
Geometry	plane SET diodes; 2.5 cm^2
Output	25 W/cm^2 (0.6 V), 21 W/cm^2 (0.7 V), 15.7 W/cm^2 (0.8 V) with efficiencies near 12.5 percent

42. Brosens, P. J.: The Influence of Design and Materials on the Performance of an Advanced Solar Converter, pp. 192-196.

Emitter	Re or Ta; T_E = 2000 K
Collector	Mo; radiation cooled (T_C near optimum)
Cesium gap	T_R optimum
Geometry	solar energy thermionics (SET) (plane); as described in the following table (from ref. 42):

DESCRIPTION OF PROTOTYPE DIFFERENCE

Prototype	100	101	102	103	104	201	202	203	204	205
Emitter material	Ta	Ta	Re	Re	Re	Re	Re	Re	Re	Re
Emitter fabrication	M	M	B	B	B	B	B	B	M	M
Emitter preparation	G	G	G	G	G	PE	PE	PE	E	E
Emitter support material	Ta	Ta	Ta	Ta	Ta	Ta	Ta	Ta	Re	Re
Collector material	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo
Collector preparation	G	L	L	L	L	L	C	C	C	M
Collector lateral area[a], cm^2	0. 5	0. 5	0. 5	1. 3	0. 5	2. 0	2. 0	1. 0	1. 0	1. 0
Nominal spacing, mm	0. 025	0. 025	0. 025	0. 025	0. 025	0. 025	0. 025	0. 025	0. 045	0. 107
Measured spacing, mm	0. 035	-----	0. 025	-----	0. 025	0. 035	0. 041	0. 033	0. 045	0. 107
Lateral spacing, mm	0. 152	0. 152	0. 152	0. 152	0. 152	0. 152	0. 152	0. 152	0. 152	0. 102
Internal radiation shield	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Compression jig	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Amperes at 0. 8 V, 2000 K	26. 5	24	42	42. 5	34	27. 8	44. 5	40	46. 5	41. 5
Amperes at 1. 0 V, 2000 K	18. 5	16. 8	32	31	27	20. 5	14	23	26	22

[a]Collector plane area, 2. 5 cm^2.

43. Bohdansky, J.; and van Andel, E.: Heat-Pipe Thermionic Converter with a Graphite Absorption Cesium Reservoir Working at Collector Temperature, pp. 239-242.

Emitter	Cl^-CVD W (110); T_E = 1755, 1825, 2000 K
Collector	Ni; T_C = 843 to 1183 K
Cesium gap	0. 10 mm; Cs, graphite reservoir at collector temperatures
Geometry	plane, ceramic guarded
Output	4. 2 W/cm^2 at 0. 5 V, T_E = 2000 K, T_C = 1183 K

44. Lieb, D.; and Kitrilakis, S. S.: Oxygen as a Steady-State Electronegative Additive in a Cesium Thermionic Converter, pp. 348-354.

Emitter	Re; T_E = 1650 to 1850 K
Collector	Mo; T_C = 573 to 773 K
Cesium gap	0. 127, 0. 254, 0. 508 mm; T_R = 481 to 538 K
Additive	Cs_2O, O_2; collector acted as Cs_2O reservoir
Geometry	plane, guarded
Output	6. 8 W/cm^2 for Cs + Cs_2O, 4. 4 W/cm^2 for Cs only at 0. 4 V, T_E = 1750 K with 0. 254-mm gap; for Cs + Cs_2O I, V curves for 0. 127 and 0. 508 mm are nearly identical at T_E = 1750 K

45. Long, J. D.; and Psarouthakis, J.: Collector Work Function Investigations in Cesium and Barium-Cesium Vapors, pp. 355-364.

Emitter	Ru; T_E = 1425° to 1627° C
Collector	Mo; Nb; Nb (O) (oxygenated Nb); Re; Ru; T_C = 390° to 570° C

Cesium gap	0.127, 0.152 mm; $T_R = 175^\circ$ to 345° C
Additive	Ba (Cs diode containing Ba shorted internally without yielding data)
Geometry	plane, unguarded; 1.18 cm^2
Output	as shown in the following table for $T_E = 1627^\circ$ C, T_R optimum, d = 0.152 mm:

Collector	Nb	Ru	Nb(O)	Re	Mo	Ru
T_C, °C	570	570	570	517	517	517
W/cm^2	11	10	10	10	8.5	6.5

---

46. Backus, C. E.; and Davis, M. V.: The Effect of Iodine and the Inert Gases as Additives in a Cesium Arc Diode, pp. 376-381.

Emitter	Ta; T_E = 1850 K
Collector	Ni; T_C = 725 K
Cesium gap	0.762 mm; T_R optimum
Additive	Ar, Kr, Xe, I
Geometry	plane; 2.38-cm diameter
Output	for Cs alone, 1.4 W/cm^2 maximum; output dropped steadily with increasing inert-gas pressure and produced at 30 torr and 0.6 V decreases of 46 percent for Ar, 76 percent for Kr, 83 percent for Xe; with I output at 0.6 V increased by 110 percent at 36 torr, then diminished to the initial (Cs only) value at 120 torr

47. Jester, A.; Gross, F.; Holick, H.; and Busse, C. A.: A Nuclear Heated Thermionic Converter, pp. 419-425.

Emitter	Mo; T_E = 1460 to 2010 K
Collector	Nb; T_C = 923 to 953 K
Cesium gap	0.204 mm; T_R optimum
Geometry	cylindric; 1.6-cm diameter, 20 cm^2
Output	9 W/cm^2 with 11 percent efficiency at T_E = 2000 K, $T_R = 360^\circ$ C (optimum); in-core performance plots

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1967.

48. Wilson, V. C.; and Lawrence, Jackson: Characteristics of a Thermionic Converter with a Fluoride Vapor Deposited Tungsten Emitter Etched to Preferentially Expose the 110 Crystal Planes, pp. 1-9.

Emitter — F^-CVD W (100) etched to expose 110 W faces and 40 percent more area; T_E = 1650 to 2150 K

Collector — Nb; T_C optimum

Cesium gap — 0.025 to 0.508 mm; T_R optimum

Geometry — plane, guarded

Output — 42 W/cm^2 with 50 A/cm^2, 20 percent efficiency and 30 W/cm^2 with 30 A/cm^2, 23 percent efficiency for d = 0.051 mm, T_E = 2155 K, T_C = 973 K; unusually high outputs at low Cs pressures and large spacings; greatest outputs came with gaps of 0.254 mm or more; good performance maps

Lifetime — performance decayed because of thermal reforming at 2155 K

49. Howard, R. C.; von Someren, L.; and Yang, L.: Preliminary Results on the Thermionic Performance of a Vapor-Deposited Tungsten Emitter Having (110) Preferred Orientation, pp. 10-12.

Emitter — Cl^-CVD W (110); T_E = 1700, 1735, 1850 K

Collector — Mo; T_C = 470° to 660° C

Cesium gap — 0.127 mm

Geometry — plane, unguarded

Output — 16 W/cm^2 at 0.5 V, T_E = 1850 K; 9.8 W/cm^2 at 0.39 V, T_E = 1700 K

50. Holland, J. W.; and Kay, J.: Performance of a Cylindrical Geometry Thermionic Converter with an Improved Work Function Tungsten Emitter, pp. 13-17.

Emitter — F^-CVD W (100); Cl^-CVD W (110); T_E = 1600° to 1800° C

Collector — Mo; Nb; T_C optimum

Cesium gap — 0.229 mm; T_R optimum

Geometry — cylindric thermionic fuel (nuclear) elements (TFE's)

Output — Cl^-CVD W emitter gave 25 percent more power than F^-CVD W; Mo collector, 40 percent more than Nb at optimum current densities

Lifetime — over 3600 hr for F^-CVD-W, Nb diode; over 6000 hr for Cl^-CVD-W, Nb diode

51. Koskinen, M. F.; and Gammel, G.: A Direct Comparison of Molybdenum and Nickel as Collector Materials, pp. 18-24.

Emitter — None

Collector — Comparison of Ni and Mo; T_C = 400° to 730° C

Cesium gap — 0.210 mm cold, 0.15 mm at 700° C; $T_R < 485$ K

Geometry — plane double-collector isothermal diode; 4 cm^2

Output — Mo collector was superior to Ni, giving 0.05 to 0.14 V lower cesiated surface potentials

52. Rufeh, F.; Lieb, D.; and Fraim, F.: Recent Experimental Results on Electronegative Additives, pp. 25-28.

Emitter	T_E = 1500 to 1900 K
Cesium gap	T_R = 433 to 638 K
Additive	CsO_2, O
Geometry	plane, fixed-gap
Output	CsO_2 increased Cs diode performance considerably; diode was run with Cs only, then with Cs + Cs_2O, and finally with Cs alone; Cs_2O improved performance, reduced Cs pressure, decreased electron scattering in gap, and allowed operation with higher diode-component temperatures; performance curves

53. Shimada, Katsunori: Apparent Work Function of Cavity Emitters, pp. 29-32.

Emitter	Ta with cavities; T_E = 1200 to 2100 K
Collector	Mo; T_C = 400° C
Cesium gap	0.051 mm; 0.324 to cavity bottoms
Geometry	plane, unguarded; 2 cm^2
Output	work functions from saturation currents and J, V curve knees were 0.4 eV lower than predicted by Rasor, Warner theory

54. Rufeh, F.; and Lieb, D.: Volt-Ampere Characteristics in the Presence of Inert Gases, pp. 33-37.

Emitter	T_E = 1800 K
Collector	T_C optimum
Cesium gap	0.254, 1.016 mm; T_R optimum
Additive	Xe, Kr, 0 to 213 torr
Output	both Kr and Xe decreased diode performance with increasing pressure; at T_E = 1800 K, d = 0.254 mm a 20 percent current drop resulted for 60 torr Xe or for 100 torr Kr; previous reports of output gains with inert gas additions probably resulted from oxygen contamination

55. Bliaux, J.; and Clémot, M.: In Pile Thermionic Life Test Sirene 302, pp. 38-46.

Emitter	CVD W; T_E = 1350° to 1700° C
Collector	Nb, 1 percent Zr; T_C = 741° to 814° C
Cesium gap	0.16 mm; T_R = 693° to over 860° C
Additive	emitter backed by 20 percent enriched UO_2
Geometry	cylindric; 4 cm long, 20 cm^2

Output	4.25 W/cm^2 with 10.6 percent efficiency at 0.78 V, T_E = 1695° C, T_C = 763° C, T_R = 810° C
Lifetime	1650 hr without degradation

56. Speidel, T.: Performance Comparison of Nine RD-502 Cylindrical Diodes with Etched Rhenium Emitters, pp. 47-50.

Emitter	etched Re
Collector	Nb; PVD Mo
Geometry	cylindric; 3.81 cm long, 15 cm^2
Output	as shown in the following table (from ref. 56):

RD-502 DIODES WITH ETCHED RHENIUM EMITTERS

Diode data									
Serial number	2	4	12	6	7	8	9	10	11
Customer	AEC	AEC	JPL	MEL	MEL	MEL	MEL	MEL	MEL
Emitter	Re	Re	Re	Re	Re	Re	Re	Re	Re
Collector	Mo	Mo	Mo	Nb	Nb	Nb	Mo	Mo	Mo
Spacing, mm	0.254	0.254	0.203	0.127	0.127	0.127	0.127	0.127	0.127
600 Watt input									
Maximum device efficiency, percent	10.1	9.8	9.2	9.4	9.0	9.2	9.0	9.4	9.2
Maximum output, W/cm^2	4.0	3.9	3.7	3.8	3.6	3.7	3.6	3.8	3.7
750 Watt input									
Maximum device efficiency, percent	12.7	11.3	12.4	12.6	---	10.8	11.2	13.2	11.7
Maximum output, W/cm^2	6.4	5.7	6.2	6.3	---	5.4	5.6	6.6	5.9
900 Watt input									
Maximum device efficiency, percent	13.8	13.5	13.8	13.3	13.2	12.5	13.3	14.5	11.5
Maximum output, W/cm^2	8.3	8.1	8.3	8.0	7.9	7.5	8.0	8.7	6.9
Life test									
Hours attained	1221	100	0	146	211	148	650	1272	1001
Stopped by	Open circuit	Program	----	Program	Water failure	Program	Program	Program	Program

57. Paquin, M. L.: Testing of a Calorimeter-Equipped Planar Thermionic Converter, pp. 51-55.

Emitter	etched Re; T_E = 1860 K
Collector	VD Mo; T_C = 973 K
Cesium gap	0.114 mm; T_R = 289° to 373° C
Geometry	plane; 1.77 cm^2
Output	as shown in the following table (from ref. 57):

DATA SUMMARY

Output voltage, volts	Input power density, W/cm^2		Output power density, W/cm^2		Device efficiency, percent	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
0.40	104	112	12.8	12.4	10.1	11.1
.40	101	101	13.7	13.3	11.1	13.2
.60	94	86	12.9	12.5	13.3	14.5
.65	58	66	9.0	8.7	12.7	13.4
.70	48	55	6.8	6.6	11.6	12.0
.75	42	49	5.5	5.3	10.5	10.5
.80	35	43	4.0	3.9	9.8	9.2

58. Brosens, Pierre J.: Advanced Converter Development, pp. 68-73.

Emitter	etched Re; T_E = 1800, 1900, 2000 K
Collector	Nb; Pd; Re
Cesium gap	0.051 mm; T_R optimum
Geometry	plane; 2.5 cm^2
Output	diode voltages decreased by averages of 0.037 V for Pd and 0.074 V for Nb relative to those for Re collector

59. Rouklove, Peter: Thermionic Converter and Generator Tests, pp. 75-85.

Emitter	Re; T_E = 1600° to 1800° C
Collector	Mo; T_C optimum
Cesium gap	T_R optimum
Geometry	plane SET diodes
Output	as shown in the following tables (from ref. 59):

Table 1. - Performance of SET-type converters

Parameters	1962	1963	1964	1965	1966	1967	Improvement factor
Power output, W	12	25	36	44	50	45	3.75
Power density, W/cm^2	6	12	18	22	20	18	3
Efficiency, percent	3	5	8	12.5	10	11	3
Maximum life, hr	119	1500	3200+	13 150+	15 210	N.A.	128
Vibration, 20 g at 0 to 2000 cps	-------	-------	-------	Passed	Passed	N.A.	------
Shock, 100 g, 0.5 msec	-------	-------	-------	Passed	Passed	N.A.	------
Power to weight ratio, W/kg	4.30	9.04	14.8	15.9	18.5	574	133
Weight/kW, kg/kW	23.2	11.1	8.66	7.08	7.68	1.74	15.1

Table 2. - Converter characteristics

Parameter	VIII-15				VIII-17				VIII-25				VIII-26			
	T_e = 1700° C		T_e = 1800° C		T_e = 1700° C		T_e = 1800° C		T_e = 1700° C		T_e = 1800° C		T_e = 1700° C		T_e = 1800° C	
E_b, v	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6	0.8	0.6
T_b, A	42.5	75.3	63.5	85.5	42.5	70.0	54.5	84.0	35.1	66.3	59.0	81.5	33.3	64.5	60.0	82.5
w, w	34	45	51	51	34	42	48	50	28	40	47	49	27	39	48	50
E_{oc}, v	2.1	1.7	1.8	1.6	1.9	1.9	1.9	1.7	2.1	1.8	1.8	1.7	2.0	1.7	1.2	1.6
w_{in}, w	344	445	469	532	330	409	434	518	311	399	447	518	302	396	462	526
Efficiency, percent	9.9	10.2	10.8	9.7	10.3	10.3	11.0	9.7	9.0	10.0	10.6	9.4	8.8	9.8	10.4	9.4
T_{cs}, °C	321	353	344	352	330	346	348	353	316	344	345	354	311	332	341	360
T_{seal}, °C	586	657	658	705	602	667	672	730	597	674	678	719	593	669	679	728
T_{col}, °C	624	764	724	850	577	683	668	720	610	737	745	819	617	762	765	873
T_{rad}, °C	540	625	622	680	533	605	612	657	530	615	617	666	524	615	617	675

60. Lazaridis, L.; Shai, I.; and Shefsiek, P.: Development of a 300-Watt Flame-Heated Thermionic Power Supply, pp. 86-92.

Emitter	W; $T_E = 1380^o$, 1425^o, 1450^o C
Collector	Ni; $T_C = 580^o$ C
Cesium gap	0.254 mm
Geometry	29 cm^2
Output	2.9 W/cm^2 at 8.6 percent efficiency, $T_E = 1380^o$ C

61. Bohdansky, J.; Salamon, K.; and van Andel, E.: Integrate Cs-Graphite Reservoir System in a Heat Pipe Thermionic Converter, pp. 93-96.

Emitter	W; T_E = 1640 to 1930 K
Collector	W; T_C optimum
Cesium gap	0.5 mm; $T_R \approx T_C$ for Cs, C compound reservoir
Geometry	plane
Output	1.8 W/cm^2 (T_E = 1640 K) to 4.1 W/cm^2 (1930 K)

62. Koskinen, M. F.; Gammel, G.; Gross, F.; DeTroyer, A.; Ne've de Mévergnies, E.; and Dejonghe, P. A. J.: An Actinium-227 Fueled Thermionic Generator, pp. 102-109.

Emitter	single crystal 110 W; T_E = 1800 K
Collector	Mo; T_C = 981 K
Cesium gap	0.2 mm; T_R = 603 K
Geometry	plane; 4 cm^2
Output	5.3 W/cm^2 at 0.53 V

63. Gronroos, Henrik G.; Davis, Jerry P.; Weaver, Lynn E.; and Guppy, James G.: A Control System Study for an In-Core Thermionic Reactor, pp. 130-137.

Emitter	W; T_E = 1500 to 2000 K
Collector	Mo; T_C optimum
Cesium gap	0.254 mm; T_R optimum
Output	SIMCON performance plots; as shown in the following table:

Emitter temperature, K	1500	1600	1700	1800	1900	2000
Power maximum, W/cm^2	1.5	2.3	3.5	5.2	7.3	9.7
Efficiency maximums, percent	7.3	9.3	10.2	12.3	13.8	15.2

64. Shefsiek, P. K.: Reproducibility of Thermionic Performance, pp. 99-102.

Emitter	Re; T_E = 1975, 2000 K
Collector	Mo; T_C = 773 to 1093 K
Cesium gap	0.051 mm; T_R = 583 to 633 K
Geometry	plane; 2 cm^2
Output	average of 12 diodes 18.8 W/cm^2 (17.5 to 20.3) at 0.7 V, T_E = 2000 K, $T_{C, ave}$ = 1045 K, $T_{R, ave}$ = 630 K

65. Merrill, O. S.: Correlation of Fixed-Spacing Thermionic Converter Performance with Variable-Spacing Test Vehicle Data, pp. 103-112.

Emitter	Re (polycrystal or vapor-deposited); T_E = 1600 to 2100 K
Collector	Re (polycrystal or vapor-deposited); T_C = 983 to 993 K and optimum
Cesium gap	0.080 to 0.305 mm; T_R = 562 to 604 and optimum
Geometry	seven plane diodes, 2 cm^2; one cylindric, 2 cm^2
Output	for 0.127 mm, maximums are 24 W/cm^2 (0.69 V, T_E = 2100 K), 20 W/cm^2 (0.60 V, T_E = 2000 K), 17 W/cm^2 (0.52 V, T_E = 1900 K), 11.4 W/cm^2 with 8.9 percent efficiency (0.41 V, T_E = 1800 K), 7 W/cm^2 (0.28 V, T_E = 1700 K); good performance curves
Lifetime	11 600 hr for one diode at 27 W/cm^2, 0.77 V, 2000 K

66. Speidel, T. O.; and Williams, R. M.: Fixed-Space Planar Thermionic Diode with Collector Guard Ring, pp. 113-117.

Emitter	Re; Ta; T_E = 1505° to 1680° C
Collector	Nb
Cesium gap	0.254 mm; T_R optimum
Geometry	plane, guarded; 1.82 cm^2
Output	not maximums but highest tested for each: 14.4 W/cm^2 (Re, 1660° C, 0.4 V), 4.2 W/cm^2 (Ta, 1680° C, 0.3 V)

67. Williams, R. M.; and Kascak, T. J.: A Comparison of the Performance of Two Rhenium, Niobium Cylindrical Thermionic Converters, pp. 118-122.

Emitter	F^-CVD Re mechanically polished or etched; T_E = 1875 to 2075 K
Collector	Nb; T_C = 973 K for T_E = 1900 K and optimum
Cesium gap	0.254 mm; T_R optimum
Geometry	cylindric; 1.28-cm diameter, 15.2 cm^2

Output   for maximum electrode efficiencies from 1875 to 2075 K, 6.8 to 9.2 W/cm^2 with 12.6 to 14.6 percent efficiency for mechanically polished Re, 5.5 to 8.3 W/cm^2 with 11.4 to 13.6 percent efficiency for electroetched Re

68. Kascak, T. J.; and Williams, R. M.: The Performance of a Rhenium, Niobium Cylindrical Thermionic Converter, pp. 123-127.

Emitter   vapor-deposited, electroetched Re; T_E = 1600 to 2050 K
Collector   Nb; T_C = 873 to 1173 K
Cesium gap   0.254 mm; T_R optimum
Geometry   cylindric; 1.27-cm diameter, 15.2 cm^2
Output   for maximum efficiency, 1.2 to 8.1 W/cm^2 with 5.2 to 13.4 percent efficiency; for maximum power, 1.4 to 8.8 W/cm^2 with 4.9 to 12.8 percent efficiency

69. Peelgren, M.; and Speidel, T.: Large Cylindrical Thermionic Diode with Rhenium Emitter for Diode Kinetic Experiments, pp. 128-133.

Emitter   etched Re; T_E = 1600° and 1770° C
Collector   Mo (Mo, Nb data in comparison); T_C optimum
Cesium gap   0.254 mm; T_R optimum
Geometry   cylindric; 1.905-cm diameter, 30 cm^2
Output   maximum power 3.8 to 9.8 W/cm^2, maximum efficiency 9.4 to 13.2 percent; results comparable with averages for six Re, Mo and three Re, Nb diodes having 0.178-mm gaps and 15-cm^2 emitters

70. Wang, C.-C.; and Ward, J. J.: Performance of Chloride and Fluoride Vapor-Deposited Tungsten Emitters in Thermionic Converters, pp. 134-140.

Emitter Cl^-CVD W (110); F^-CVD W (100); etched F^-CVD W (110); T_E = 1600 to 2000 K
Collector   Nb; T_C optimum
Cesium gap   0.203 mm; T_R optimum
Geometry   six plane diodes
Output   as shown in the following table for polycrystalline 110 types at 10 A/cm^2:

T_E, K	1600	1700	1800	1900	2000
W/cm^2	1.8 to 2.7	3.0 to 4.4	4.8 to 5.5	5.8 to 7.0	7.4 to 8.6

above 1800 K Cl^-CVD W gave 50 percent higher power densities than F^-CVD W; below 1700 K Cl^-CVD W performed better only at low output voltages; etching raised F^-CVD W outputs to those of Cl^-CVD W; good performance maps

71. Rufeh, F.; and Lieb, D.: Emission Characteristics of a Duplex Vapor-Deposited Tungsten Emitter, pp. 141 to 150.

Emitter	Duplex W (Cl^-CVD on F^-CVD); T_E = 1600 to 1915 K
Collector	Mo; T_C = 900 and 950 K
Cesium gap	0.013 to 1.016 mm; T_R's giving 0.5 to 11 torr
Geometry	plane, guarded
Output	excellent performance maps; for optimum spacings and cesium pressures at 10 A/cm^2 output was as follows:

T_E, K	1600	1700	1800	1900
T_C, K	900	900	950	950
W/cm^2	2.8	3.8	5.6	7.2

72. Ernst, D. M.: Performance Comparison of Four Cylindrical Diodes with Various Types of Tungsten Emitters, pp. 151-154.

Emitter	F^-CVD W (100): (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground; T_E = 1800° C or less
Collector	Nb; T_C optimum
Cesium gap	0.254 mm; T_R optimum
Geometry	1.27-cm diameter, 15 cm^2
Output	as shown in the following table:

Diode, φ, eV	1 4.88	2 4.55	3 4.58	4 4.75
600 W input				
Maximum efficiency, percent	7.7	9.3	7.8	9.0
Maximum power, W/cm^2	3.1	3.8	3.1	3.6
750 W input				
Maximum efficiency, percent	8.9	10.2	9.3	9.7
Maximum power, W/cm^2	4.5	5.1	4.6	4.9
900 W input				
Maximum efficiency, percent	9.8	11.0	10.1	10.2
Maximum power, W/cm^2	5.8	6.6	6.1	6.2

73. Shimada, K.: Side-Wall Currents in Unignited Hardware-Type Thermionic Energy Converters, pp. 155-158.

Emitter	Re; T_E = 1700 to 2016 K
Geometry	SET plane diode
Output	side-wall-current theory agrees with test results

74. Stapfer, G.; and Shimada, K.: Electrical Testing of a Six-Converter Generator, pp. 159-163.

Emitter	Re; T_E = 1600^o and 1700^o C
Collector	Mo; T_C near optimum (radiation cooling)
Cesium gap	T_R optimum
Geometry	six SET plane diodes in a generator, 2 cm^2 each
Output	for the generator, 140 W at 3.0 V (4.0 V without lead losses), 4.5 percent efficiency, T_E = 1700^o C; 96 W at 3.0 V (3.75 V without lead losses), 4.5 percent efficiency (at 3.5 V), T_E = 1600^o C; averages for the diodes, 11.7 W/cm^2 at 0.67 V, T_E = 1700^o C; 8 W/cm^2 at 0.62 V, T_E = 1600^o C

75. Hansen, L. K.: Thermionic Research at Stresa (A Review), pp. 178-187.

Emitter	T_E = 1800 K
Collector	T_C optimum

Cesium gap	0.254 mm; T_R optimum
Additive	Ar, Xe
Output	additions of inert gases only degrade diode performance; at 10 A/cm^2 40 torr of Ar caused a drop from 3.4 W/cm^2 to 2.4 W/cm^2

76. Dagbjartsson, S.; Groll, M.; Schlörb, O.; and Pruschek, R.: An Improved Out-of-Core Thermionic Reactor for Low Power, pp. 299-304.

Emitter	Re; T_E = 1850 K
Collector	Mo probably
Output	18 W/cm^2

77. Lieb, D.; and Rufeh, F.: Thermal Stability as a Function of Converter Performance, pp. 318-322.

Emitter	T_E = 1600 to 2000 K
Cesium gap	0.127 to 0.305 mm; T_R = 548 to 635 K
Output	I, V curves for high- and low-performance diodes used to show that above-optimum T_R's insure against in-core thermal runaway

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1969.

78. Jacobson, Dean L.; and Campbell, A. E.: The Characterization of Bare and Cesiated CVD 75 Percent Tungsten/25 Percent Rhenium Electrodes, pp. 26-33.

Emitter	75 percent W, 25 percent Re; T_E = 1800, 2000 K
Collector	75 percent W, 25 percent Re; T_C = 927 to 1000 K
Cesium gap	0.003 to 0.762 mm; 0.254-mm fixed gap; T_R = 588 to 650 K
Geometry	variable-parameter, plane, guarded diode; fixed-gap plane diode; cylindric diode; each 2 cm^2
Output	16 W/cm^2 at 0.5 to 0.6 V, T_E = 2000 K for fixed-gap plane diode; 18 W/cm^2 at 0.4 to 0.5 V, T_E = 2000 K for cylindric diode

79. Pigford, Thomas H.; and Thinger, Byron E.: Performance Characteristics of a 0001 Rhenium Thermionic Converter, pp. 34-38.

Emitter	1-xtal 0001 Re; T_E = 1600 to 2000 K
Collector	Nb; T_C = 933 K
Cesium gap	0.254 mm; T_R = 507 to 611 K
Geometry	plane, guarded; 0.621 cm^2

Output maximum electrode power densities, 5.1 W/cm^2 at T_E = 1600 K to 15.4 W/cm^2 at T_E = 2000 K; at 10 A/cm, T_C = 933 K, T_R = optimum, power density was as follows:

T_E, K	1600	1700	1800	1900	2000
W/cm^2	3.6	5.2	6.7	7.8	9.3

80. Wilson, V. C.; and Danko, J. C.: Development of a Stable Faceted Tungsten Emitter Surface, pp. 46-52.

Emitter F^-CVD W (100) etched to 110 faces (compared with polycrystalline W, 100 W, and 112 to 114 W); T_E = 1650 to 2150 K
Collector Nb; T_C optimum
Cesium gap spacing optimum; T_R optimum
Geometry plane, guarded
Output 4.2 W/cm^2 at 10 A/cm^2 and T_E = 1650 K to 13.9 W/cm^2 at 10 A/cm^2 and T_E = 2150 K
Lifetime 150 hr with no effect at 1980 K; surface changed after 22 hr at 2130 K

81. Lieb, D.; Donaker, A.; and Rufeh, F.: Performance of a Thermionic Converter with a Nominal Single-Crystal ⟨110⟩ Tungsten Emitter and a Niobium Collector, pp. 66-75.

Emitter 110 W (several crystals with 110 faces within 4^o of emitter surface); T_E = 1600 to 2000 K
Collector Nb; T_C = 700 to 1025 K
Cesium gap 0.013 to 1.016 mm; T_R = 528 to 653 K
Geometry plane, guarded
Output performance is better than that for a high-output Cl^-CVD W dicde below 0.47 V at T_E = 1700 K and below 0.8 V at T_E = 1900 K; excellent performance maps; fully optimized at 10 A/cm^2; power as shown in the following table:

T_E, K	1600	1700	1800	1900	2000
W/cm^2	3.1	4.7	6.2	7.8	10.0

82. Wilson, V. C.: A Review of Thermionic Converter Tests, pp. 82-89.

Emitter	several orientations and surface preparations for W and for Re; W, 25 percent Re; Mo; Ta; T_E = 1650 to 2150 K
Collector	W + WO_2 on Nb; Mo; Nb; Ni; Re; T_C optimum
Cesium gap	0.051 to 0.508 mm and optimum; T_R = 513 to 633 K and optimum
Geometry	plane
Output	excellent condensation and comparison of output results mostly for high-performance diodes

83. Breitwieser, Roland; Manista, Eugene J.; and Smith, Arthur L.: Computerized Performance Mapping of a Thermionic Converter with Oriented Tungsten Electrodes, pp. 90-99.

Emitter	single-crystal 110 W; T_E = 1550 to 1950 K
Collector	single-crystal 110 W; T_R = four temperatures around peak-power point
Cesium gap	0.025 to 0.305 mm; T_R = 520 to 600 K
Geometry	plane, guarded; 1.02-cm diameter
Output	for 0.203 mm and T_R = 600 K maximums were 3 W/cm^2 at 0.4 V, T_E = 1750 K; 3.8 W/cm^2 at 0.4 V, T_E = 1850 K

84. Clemot, M.; Gayte, B.; Lebourg, R.; and Tripet, J.: Life Testing and Performance Stability of Cylindrical Thermionic Converters, pp. 100-108.

Emitter	F^-CVD W (100); T_E = 1300° to 1650° C
Collector	Mo or Nb, 1 percent Zr; T_C optimum
Cesium gap	0.20 to 0.25 mm; T_R optimum
Geometry	cylindric, 20 cm^2
Output	as shown in the following table (from ref. 84):

Serial number	COL 130	COL 135	COL 134	COP 140	312	314	308	310
Emitter Collector Cold spacing, μ	Mo/W, 60 μ Mo 230	Mo Mo 250	Mo/W, 85 μ Mo 200	Mo/W, 150 μ Mo 200	Mo/W, >200 μ Nb, 1% Zr 200	W, 2 mm Nb, 1% Zr 200	Mo/W, >200 μ Nb, 1% Zr 200	Mo/W, >200 μ Nb, 1% Zr 200
$p_E = 40\ W/cm^2$, $T_E \approx 1470^\circ$ C								
Maximum total efficiency, percent	11.3	8.7, 15	10	11.8	9.3	9.5	8.5	8.2
Maximum output, W/cm^2	4.5	3.45, 6	4	4.7	3.7	3.84	3.4	3.3
$p_E = 50\ W/cm^2$, $T_E \approx 1600^\circ$ C								
Maximum total efficiency, percent	11.8	9.4, 16	11	14	10	9.6	9.9	10.3
Maximum output, W/cm^2	5.9	4.7, 8	5.5	7	5	4.8	4.9	5.15
Life tests, hr	4600	1125	5256	1860	2400	1100	8500	5000
Cause of failure	S. C., W emitter peeling off and blistering	S. C., Mo emitter transport	S. C., W emitter had localized blisters	S. C., W emitter had localized blisters	S. C.	Cs leak at the E, C insulator	Still running	Voluntarily stopped
Remarks	Bad CVD condition (WCl_6), first S. C. at 3300 hr	High performance followed by rapid degradation	W transport material (emitter to collector)	W transport material (emitter to collector)	Under post-test examination	Under post-test examination		Water leak in environment

85. Gunther, B.: Converter Performance Comparison, pp. 109-114.

Emitter	F^-CVD W (100); T_E = 1600 to 2000 K
Collector	Nb; T_C optimum
Cesium gap	0.254 mm; T_R = 330° to 400° C
Geometry	12 cylindric diodes, each 20 cm^2
Output	as shown in the following table (with a 3.7 percent standard deviation):

T_E, K	1760	1860	1960
P_{max}, W/cm^2	3.0	4.6	5.9
η_{max}, percent	7.5	9.2	9.9

86. Samstad, G. I.; Case, J. M.; and Danko, J. C.: Design, Operation and Post-Test Analysis of a High Performance Cylindrical Converter, pp. 115-121.

Emitter	Cl^-CVD W (110); $T_E \approx$ 1700° C
Collector	Nb; $T_C \approx$ 700° C
Cesium gap	0.254 mm; T_R = 340° to 372° C
Geometry	cylindric; 1.42-cm diameter, 11.0 cm^2
Output	7.4 W/cm^2 maximum at T_E = 1700° C, T_C = 700° C, T_R = 360° C; 9.5 W/cm^2 maximum at T_E = 1710° C, T_C = 710° C, T_R = 354° C after 5000 hr
Lifetime	removed after 5000 hr for examination

87. Hamerdinger, Randolph W.; and Jacobson, Dean L.: Design and Performance of Low Temperature Cylindrical Thermionic Converters, pp. 122-129.

Emitter	Cl^-CVD Re; T_E = 1573, 1673, 1800 K
Collector	Cl^-CVD Re; T_C = 875 to 976 K and optimum
Cesium gap	0.152 mm (2 cm^2), 0.203 mm (4 cm^2); T_R = 582 to 612 K and optimum
Geometry	cylindric; two with 2-cm^2 emitters, three with 4-cm^2 emitter
Output	10.3 W/cm^2 at T_E = 1800 K for 2 cm^2, 4.25 W/cm^2 at 1673 K for 4 cm^2

88. Bliaux, J.; Marquer, P.; Dumas, P.; Leclerc, A.; Desmarest, C.; and Ducrocq, D.: In Pile Life Testing of Thermionic Converter Sirene 311, pp. 130-140.

Emitter	F^-CVD W (100) on Mo (backed by enriched UO_2); T_E = 1560° C (out of core), 1601° C (in core)

Collector Nb, 1 percent Zr; $T_C = 632^\circ$ C (out of core)

Cesium gap 0.2 mm; T_R optimum for Cs, C compound reservoir

Geometry cylindric; 20 cm^2

Output out of core, 5 W/cm^2 at 10 percent efficiency; in core, 4.6 W/cm^2 at 8.5 percent efficiency

Lifetime 4740 hr in 6-MW reactor (2×10^{12} N/cm^2), 3800 hr with no degradation; test terminated by emitter shortout

89. Jester, A.; Holick, H.; Krapf, R.; and Zöller, R.: Thermionic Converter Development for ITR, pp. 141-144.

Emitter Mo (with and without UO_2 backing); $T_E = 1400^\circ$ to 1700° C

Collector $T_C = 600^\circ$ to 700° C

Cesium gap $T_R = 350^\circ$ to 370° C and optimum

Output and lifetime in-core test: UO_2 fueled emitter at 1400° to 1500° C, collector at 600° to 700° C, and reservoir at 350° C gave 3.5 to 5 W/cm^2 at 0.5 to 0.6 V for 3750 hr; out-of-core tests: as shown in the following table (from ref. 89):

OUT-OF-CORE TESTS[a]

Diode	Emitter material	Emitter dimensions, mm		Collector material	Metal, ceramic seal	Life time, hr	Remarks
		Diameter	Length				
1	Sintered Mo	16	40	Sintered Mo	E2: Mo, Mn	300	Ceramic destroyed by cesium attack; shrinking of emitter diameter 0.1 mm
2	Sintered Mo	16	40	Sintered Mo	E2: Mo, Mn	300	Operated as vacuum diode; shrinking of emitter diameter 0.1 mm
3	Arc cast Mo	16	40	Sintered Mo	E37: Mo, Mn	1 100	Leak in metal, ceramic seal
4	Arc cast Mo	16	40	Sintered Mo	E37: Mo, Mn	[b]>16 000	Still operating
5	Arc cast Mo	20	54	Sintered Mo	E37: tungsten metallizing	>7 000	Still operating; dimensions of electrodes as proposed for ITR
6	Arc cast Mo	16	40	Sintered Mo	E37: tungsten metallizing	>4 000	Still operating; emitter fueled with UO_2 powder
		UO_2 in 15 bore hole in the emitter wall					
7	Arc cast Mo	20	54	Sintered Mo	E37: tungsten metallizing	>4 000	Still operating; dimensions of electrodes and metal ceramic seal for ITR

[a]All diodes 4 to 5 W/cm^2 at T_E's from 1650° to 1700° C and T_R optimums from 360° to 370° C - except six in which "electrical output was high and the optimum cesium temperature was low," "attributed to excess oxygen diffusing through the emitter . . ."

[b]Valid for electrodes and metal, ceramic seal; cesium reservoir replaced after 3000 hr because of a leak.

90. Ernst, D. M.: Life Test Results from Cylindrical Diodes with Tungsten Emitters, pp. 146-149.

Emitter	F^-CVD W (100) (1) as-deposited, (2) etched as-deposited, (3) as-ground, (4) etched as-ground
Collector	Nb; T_C optimum
Cesium gap	0.254 mm; T_R optimum
Geometry	cylindric, 1.27-cm diameter, 15 cm^2
Output	for 50 W/cm^2 input and 8 A/cm^2: (1) 4.7 W/cm^2, (2) 5.1 W/cm^2, (3) 4.4 W/cm^2, (4) 4.5 W/cm^2; see ref. 72
Lifetime	(1) 6550 hr, (2) 6200 hr, (3) 5850 hr, (4) 5250 hr

91. Stapfer, Gerhard: Thermionic Converter Life-Test Program, pp. 150-156.

Emitter	Re; T_E = 1800, 1900, 2000 K
Collector	Mo, Re; T_C near optimum (radiation cooled)
Cesium gap	T_R optimum
Geometry	10 plane SET diodes
Output	as shown in the following table (from ref. 91):

Converter life-test performance

Converter	Design, T_E, K	Operating, T_E, K	Electrode material	Collector area, cm^2	Average, P_{OUT}, W/cm^2	E_{OUT}, v	Efficiency, percent	Thermal cycles	Operating time, hr	Failure mode
SN-101	2000	2000	Re, Re	1.88	25.0	0.7	10.0	195	20 700	Operating
SN-103	2000	2000	Re, Mo	1.88	21.0/10.0	0.7/0.5	9.0/5.5	15	7 168	Open circuit
SN-108	1900	2000	Re, Re	1.88	18.0	.7	7.7	0	1 247	Open circuit
T-VIII-7	2000	2000	Re, Mo	2.0	17.0	.7	7.5	10	8 326	Operating
T-VIII-12	2000	2000	Re, Mo	2.0	17.0	.7	7.5	9	6 421	Operating
T-VIII-16	2000	2000	Re, Mo	2.0	16.0	.7	7.0	14	8 100	Operating
TE-206	2000	2000	Re, Re	2.0	7.0	.7	4.0	7	11 470	Operating
VIII-S-23	2000	2000	Re, Mo	2.0	12.1	.7	6.9	2	740	Discontinued
VIII-S-20	2000	1800	Re, Mo	2.0	6.6	.7	5.0	2	2 944	Discontinued
VIII-S-9	2000	1900	Re, Mo	2.0	9.8	.7	5.5	8	1 200	Discontinued

92. Kascak, Thomas J.; Williams, Richard M.; and Kroeger, Erich W.: The Performance of a Molybdenum, Molybdenum Cylindrical Thermionic Converter, pp. 157-162.

Emitter	Mo; T_E = 1500 to 1750 K
Collector	Mo; T_C = 873 to 1063 K
Cesium gap	0.254 mm; T_R = 515 to 555 K
Geometry	cylindric; 1.27-mm diameter, 15.2 cm^2
Output	as shown in the following table (from ref. 92):

DIODE OUTPUT FOR MAXIMUM EFFICIENCY AND MAXIMUM

POWER DENSITY CONDITIONS

Emitter temperature, K	At maximum efficiency			At maximum power density		
	Electrode efficiency, percent	Electrode voltage, v	Power density, W/cm^2	Electrode efficiency, percent	Electrode voltage, v	Power density, W/cm^2
1500	2.1	0.12	0.6	2.0	0.09	0.7
1600	5.3	.26	1.8	4.9	.20	2.0
1750	8.4	.46	3.3	7.9	.36	3.6

93. Wilkins, D. R.; Wurm, J. P.; Derby, S. L.; and McCandless, R. J.: A Theoretical Study of Methods for Improving Thermionic Converter Performance, pp. 198-205.

Emitter	polycrystalline W; T_E = 1640 to 1950 K
Collector	polycrystalline Mo; T_C = 840 to 910 K
Cesium gap	0.152 to 0.508 mm; T_R = 571 to 635 K
Geometry	plane
Output	SIMCON correlation and performance maps

94. Rufeh, Firvoz; and Lieb, David: The Dependence of the Volt-Ampere Characteristics on Collector Temperature, pp. 237-246.

Emitter	Cl^-CVD W (110) (on F^-CVD W (100)); T_E = 1800, 1500, >>1300 K
Collector	Mo; T_C = 605 to 1022 K
Cesium gap	0.013 to 0.635 mm; T_R = 461 to 620 K
Geometry	plane, guarded
Output	study of collector effects on diode voltage (work function) and current (back emission) indicates that present theories are not adequate

95. Peelgren, M. L.; and Ernst, D.: Thermionic Diode Kinetics Experiment - Design and Startup, pp. 434-443.

Emitter	Re; $T_E = 1850^\circ$ C maximum, 1800° C average
Collector	Mo; $T_C = 700^\circ$ C
Geometry	four cylindric diodes, each 30 cm^2
Output	nominally 8.4 W/cm^2 at 0.6 V and 12 percent efficiency

96. Imbert, F.; and Shroff, A. M.: Thermionic Integrated Cesium Reservoir Module, pp. 528-534.

Emitter	CVD W; $T_E = 1370^\circ$ to 1790° C
Collector	Mo; T_C optimum
Cesium gap	0.2 mm; T_R from Cs, C reservoir coupled to collector (T_C optimums occur within 50° C around 700° C)
Geometry	cylindric
Output	over 10 percent efficiency
Lifetime	1000 hr and continuing

Conference Record of the Thermionic Conversion Specialist Conference. IEEE, 1970.

97. Dunlay, J.; and Meyers, R.: Emitter and Collector Sublimed Coatings, pp. 86-89.

Emitter	PVD W (110) (on F^-CVD W (100)); T_E = (1) 1700 K, (2) 1800 K, (3) 1900 K
Collector	Nb; T_C optimum
Cesium gap	0.254 mm; T_R optimum
Geometry	plane
Output	at 10 A/cm^2 (1) 4.3 W/cm^2, (2) 5.7 W/cm^2, (3) 7.0 W/cm^2, which equal outputs for single-crystal 110 W

98. Kuznetsov, V. A.: In-Pile Tests of Multielement Thermionic Converters with Molybdenum - and Tungsten - Based Cathodes, pp. 196-202.

Emitter	Mo; "Mo-based alloy"; "W-based alloy"; "W, Re"; $T_E = 1300^\circ$ to 1700° C
Collector	Nb; $T_C = 600^\circ$ to 700° C
Cesium gap	0.4 to 0.5 mm; 2 to 19 torr
Geometry	multielement assemblies; five or six axially alined diodes with cylindric emitters, each having a plane active end
Output and lifetime	as shown in the following table (from ref. 98):

Converter number	Number of elements	Cathode can material	Cathode temperature, °C	Electric power density, W/cm^2	Time of in-pile experiment, hr
TIC-21	5	Molybdenum-based alloy	1600	[a]1.8 to 2.2	2750 [b](2200)
TIC-28	5	Molybdenum monocrystal	1600	2.7	1400 [b](1100) Experiment is continued
TIC-20	5	Tungsten-based alloy	1850 to 1900	7.8	900 [b](650)
ES-6-1	6	Tungsten, rhenium	1850	6 to 7	75
ES-6-2	6	Tungsten, rhenium	1950	10	220

[a]Efficiency, 9+ percent.
[b]Time of maximum electric-power operation.

99. Rufeh, F.; Gunther, B.; and Lieb, D.: Collector Work Function Measurements, pp. 233-242.

Emitter T_E = 575 to 1800 K
Collector Mo; Nb; T_C = 670 to 775 K, T_C/T_R = 1.1 to 2.5
Cesium gap 0.013 to 1.016 mm; T_R = 428 to 516 K, T_R/T_C = 0.4 to 0.91
Output collector effects on diode performance (see ref. 94); present theories still fail to predict collector influences on outputs

100. Hansen, Lorin K.: Non-Saturation Phenomena in Thermionic Converters, pp. 305-311.

Emitter single-crystal 110 Mo; T_E = 1600, 1682 K
Collector single-crystal 110 Mo; T_C = 850 K
Cesium gap 0.127 to 1.27 mm; T_R = 500 to 580 K
Geometry plane, guarded
Output 1.7 W/cm^2 at 0.65 V, T_E = 1682 K, T_C = 850 K, T_R = 548 K

101. Rouklove, Peter: Radioisotope Thermionic Generator (RTIG), pp. 382-387.

Emitter Re; T_E = 1573 to 1773 K
Collector Nb; T_C = 951 K for 0.5 V
Cesium gap 0.762 mm (hot); T_R = 594 to 595 K for 0.5 V
Geometry cylindric; 4 cm^2
Output at 1673 K design point 3.5 to 4.4 W/cm^2 at 0.5 V, 4.2 to 4.6 W/cm^2 at 0.4 V; at 10 A/cm^2 outputs were as follows:

T_E, K	1573	1673	1713	1773
W/cm^2	3.3	4.2	4.8	5.2

102. Gunther, B.: Emitter Temperature Dependence of Lower Mode Current, pp. 446-452.

Emitter	110, Cl^-CVD (110); F^-CVD (100) W; T_E = 1600 to 1850 K
Collector	Nb; T_C = 760 to 930 K
Cesium gap	0.054 to 0.508 mm; T_R = 530 to 660 K
Geometry	plane, guarded; 2 cm^2
Output	apparent lower-mode saturation currents (at or near ignition); limited by electronic space charge and by collisions; used to determine emitter temperatures (for in-core diodes)

103. Gronroos, H. G.; and Sawyer, C. D.: Reactor Simulator Runs with Thermionic Diode Kinetics Experiment, pp. 453-461.

Emitter	Re; T_E = 1300° to 1700° C
Collector	Nb; T_R not optimum
Cesium gap	0.254 mm; T_R = 293° C (near optimum initially)
Geometry	cylindric; 1.9-cm diameter, 5.08 cm long
Output	3.3 W/cm^2 at 0.5 V, T_E = 1700° C (not optimum, used for kinetics input to reactor simulator)

104. Rufeh, F.; and Lieb, D.: Thermionic Performance of Fluoride CVD Tungsten-Niobium Converter, pp. 462-470.

Emitter	F^-CVD W (100) (compared with Cl^-CVD W (110), Mo; single-crystal 110 W, Nb; or single-crystal-110 W, Mo, O_2 diode); T_E = 1600 to 2000 K
Collector	Nb (Mo or Nb); T_C = 670 to 1010 K
Cesium gap	0.013 to 1.03 mm; T_R = 480 to 655 K
Additive	O_2 in the single-crystal 110 W, Mo diode
Geometry	plane, guarded; 2 cm^2
Output	I, V performance maps for F^-CVD-W, Nb diode; at T_E = 1800 K, 0.254 mm spacing, 10 A/cm^2 output was as follows:

Diode	F^-CVD-W, Nb	Cl^-CVD-W, Mo	1-xtal-110-W, Nb	1-xtal-110-W, Mo, O_2
W/cm^2	2.7	4.8	5.8	7.6

105. Lieb, D.; and Rufeh, F.: Thermionic Performance of CVD Tungsten Emitters with Several Collector Materials, pp. 471-480.

Emitter	Cl^-CVD W (110); F^-CVD W (100); single-crystal 110 W; T_E = 1600 to 2000 K
Collector	Mo (polycrystalline or PVD (110)) or Nb; T_C = 970 to 1023 K
Cesium gap	0.025 to 2.032 mm; T_R = 539 to 653 K
Additive	O_2 in single-crystal 110 W, Mo diode
Output	good I, V curves for Cl^-CVD W, Nb; from 1700 to 1900 K with 0.254 mm spacing and 10 A/cm^2 output was as follows:

Diode	1-xtal-110 W, Mo, O_2	1-xtal-110 W, Nb	Cl^-CVD W, Mo	F^-CVD W, Nb
W/cm^2	5.8 to 9.0	4.5 to 7.0	4.0 to 6.3	1.7 to 3.7

106. Samstad, G. I.; Danko, J. C.; and Levin, H. A.: Performance of Cylindrical Converter with Deep Etched Tungsten Emitter, pp. 481-486.

Emitter	Electroetched F^-CVD W (110) (compared with both Cl^-CVD (110) and F^-CVD (100) W); T_E = 1400^o, 1500^o, 1700^o C
Collector	Nb; T_C = 600^o, 800^o, 950^o, 1000^o C
Cesium gap	0.3 mm; T_R = 320^o to 377^o C
Geometry	cylindric; 1.41-cm diameter, 11 cm^2
Output	3.2 to 7.6 W/cm^2 for 1400^o to 1700^o C with T_R optimum and T_C near optimum at 10 A/cm^2; performance curves and comparisons; electroetched F^-CVD W (110) gave outputs comparable with those for Cl^-CVD W (110)
Lifetime	output was stable for 5000 hr at 1700^o C

107. Lancashire, Richard B.: Computer-Acquired Performance Map of an Etched-Rhenium, Niobium Planar Diode, pp. 487-491.

Emitter	etched Re; T_E = 1550 to 2050 K
Collector	Nb; T_C = 750 to 1180 K
Cesium gap	0.254 mm; T_R = 525 to 650 K
Geometry	plane, guarded
Output	maximum efficiencies, 7.3 to 16 percent from 1600 to 2000 K; at 10 A/cm^2 with T_C and T_R optimum output was as follows:

T_E, K	1600	1700	1800	1900	2000
W/cm^2	2.1	4.1	5.7	7.8	9.1

108. Ernst, Donald M.: Thermionic Performance of CVD Chloride Tungsten and Sublimed Coated Molybdenum Electrodes in Cylindrical Heat Pipe Diodes, pp. 492-497.

Emitter Cl$^-$CVD W (110); T_E = 1600 to 1900 K
Collector PVD Mo (110); T_C = 292° to 640° C
Cesium gap 0.254 mm; T_R = 245° to 305° C
Geometry five cylindric diodes, each 1.9-cm diameter and 20 cm^2
Output at 10 A/cm^2 with T_C and T_R optimum output was as follows:

T_E, K	1600	1700	1800	1900
W/cm^2	3.2	5.3	7.4	9.2

this high performance was stable through 100 hr of initial testing

109. Yates, M. K.; Fitzpatrick, G. O.; and Kay, J., Jr.: Long Term Operation of Out-of-Pile Thermionic Converters, pp. 498-507.

Emitter (1) Cl$^-$CVD W (110) (standard Cs reservoir), (2) F$^-$CVD W (100) (graphite, Cs reservoir); (1) T_E = 1700° C, (2) T_C = 1760° C
Collector Nb; (1) T_C = 799° C, (2) 701° C
Cesium gap (1) 0.229 mm, (2) 0.203 mm; (1) T_R = 352° C, (2) 814° C (C, Cs reservoir)
Geometry cylindric (1) 2.54 cm long, 16.1 cm^2; (2) cylindric, 5.08 cm long, 26.7 cm^2
Output (1) 8.0 W/cm^2 at 14 percent efficiency, (2) 6.8 W/cm^2 at 12 percent efficiency

110. Shroff, A. M.; and Imbert, F.: Integrated Cesium Reservoir Thermionic Converter for In-Pile Applications, pp. 508-512.

Emitter W (apparently)
Collector Mo (apparently); $T_C \approx$ 650 K
Cesium gap 0.2 mm (apparently); T_R near T_C for Cs, C reservoir
Output maximum experimental value, 6.2 W/cm^2

111. Knauss, G.: A Longlife Thermionic Diode with Barium and Cesium Vapors, pp. 513-516.

Emitter	polycrystalline W; T_E = 1800, 1900, 1950 K
Collector	Ta; T_C = 920 to 1120 K
Cesium gap	0.1 to 2.5 mm; T_R = 390 to 473 K, P_{Cs} = 0
Additive	Ba; T_{Ba} = 900 to 1100 K
Geometry	plane
Output	several I, V figures; at T_E = 1900 K, T_C = 1120 K, T_{Ba} = 1100 K, T_{Cs} = 473 K maximum outputs occurred at 0.1 mm spacing; for these conditions, 8.5 W/cm^2 at 13 A/cm^2 was approximate maximum

112. Schock, A.; Raab, B.; and Giorgio, F.: Design, Fabrication, and Testing of a Full-Length External-Fuel Thermionic Converter, pp. 517-532.

Emitter	W (backed with enriched UO_2); $T_E \approx$ 1900 to 2100 K
Collector	Nb; T_C optimum
Cesium gap	0.254 mm; T_R optimum
Additive	U and O possible
Geometry	cylindric; 1.27-cm diameter, 20.32 cm long
Output	7.1 W/cm^2 (9.8 A/cm^2) at 11.5 percent efficiency with T_E = 1940 K, T_R = 531 K

113. Ernst, D. M.: Design, Fabrication and Testing of Externally Configured Thermionic Diodes, pp. 533-538.

Emitter	F^-CVD W (100); T_E = 1800 to 2070 K
Collector	Mo; T_C = 675^o to 845^o C
Cesium gap	0.254 mm; T_R = 290^o to 333^o C
Geometry	cylindric; 1.14-cm diameter, 84 cm^2
Output	4.1 to 6.2 W/cm^2 at 6 A/cm^2, T_E = 1900 to 2070 K

114. Teagan, W. Peter: The Development of Thermionic Diodes for Isotope-Fueled Generators, pp. 539-545.

Emitter	etched Re (compared with 0001 Re with and without O_2); T_E = 1600^o C
Collector	Mo; T_C = 600^o C
Cesium gap	0.127 mm; T_R optimum
Additive	O_2 with 0001 Re
Geometry	plane; 13.3 cm^2

Output	4.5 W/cm^2 (0.9 V) to 9.6 W/cm^2 (0.4 V); maximum electrode efficiency of 15 percent with 7.9 W/cm^2 at 0.7 V (0001 Re at 1900 K with T_R optimum and 0.254-mm spacing produced 11.9 W/cm^2 and with O_2 17.5 W/cm^2 both at 0.7 V, 8.8 W/cm^2 and with O_2 10.3 W/cm^2 both at 10. A/cm^2)
Lifetime	3000 hr at maximum-electrode-efficiency point with no change

115. Kroeger, Erich W.: Fabrication and Evaluation of an Out-of-Core Thermionic Converter Module, pp. 546-549.

Emitter	Cl^-CVD Re; T_E = 1600 to 1700 K
Collector	Nb, 1 percent Zr
Cesium gap	0.229 mm
Geometry	cylindric; 10.16 cm long, 73.7 cm^2
Output	better than that for a polycrystalline-Re, Nb diode

116. Clémot, M.; Gayté, B.; and Lebourg, R.: Post Test Examinations of a Long Life Thermionic Converter, pp. 556-561.

Emitter	CVD W; T_E = 1820 K
Collector	Mo; T_C = 840 K
Cesium gap	0.2 mm; T_R = 575 K
Geometry	cylindric; 20 cm^2
Output	7.5 W/cm^2 at 12.5 percent efficiency
Lifetime	Emitter, collector short circuit after 9000 hr. "In any case, the failure was accelerated by material transport from the emitter to the molybdenum collector. This may be avoided by using converters with Nb, 1 percent Zr collectors gettering O_2 present in the interelectrode spacing."

Conference Record of the Thermionic Conversion Specialist Conference. IEEE. 1971.

117. Yates, M. K.; Holland, J. W.; Allen, D. T.; Fitzpatrick, G. O.; Grebetz, J. C.; and Horner, M. H.: Thermionic Fuel Element Development Program Status, pp. 68-77.

Emitter	Cl^-CVD W (110); T_E = 1500°, 1600° C
Collector	Nb; T_C optimum
Cesium gap	T_R optimum
Additive	U and O or C possible
Geometry	cylindric TFE's
Output	as shown in the following table (from ref. 117):

TFE TEST HISTORY

	TFE 2E1	TFE 2E2	TFE 2E3	TFE 6F1	TFE 1F1	TFE 1F2
Emitter	W (110)	W (110)	W (110)	W (110)	W (110)	W (110)
Collector	Nb	Nb	Nb	Nb	Nb	Nb
Fuel	UO_2	UO_2	UC, ZrC	UC, ZrC	UO_2	UC
Number of cells	2	2	2	6	1	1
Test duration, hr	[a]9700	[a]200	3661	[a]1000	[a]200	[a]1000
Average electrode power density, W/cm^2	5	6	3	2	4	4
Average emitter temperature, ^{o}C	1600	1600	1500	1600	1500	1600
Failure mode	(a)	(a)	Envelope leak	(a)	(a)	(a)

[a]Still in operation 9/71.

118. Shimada, K.; and Rouklove, P.: Reactor Core Length, Externally Configured Thermionic Converter, pp. 110-115.

Emitter	F^-CVD W (100); T_E = 1638 to 1942 K
Collector	Mo; T_C = 885 to 945 K
Cesium gap	T_R = 565 to 633 K
Geometry	cylindric; 1.14-cm diameter, 91.2 cm^2
Output	1.95 W/cm^2 with 5.5 percent efficiency at T_E = 1942 K, T_C = 900 K, T_R = 633 K

119. Schock, A.; and Raab, B.: Development of a Full-Length External-Fuel Thermionic Converter for In-Pile Testing, pp. 116-127.

Emitter	W, 2 percent ThO_2 (enriched UO_2 backed in core, not here); T_E = 1650° to 1700° C
Collector	T_C optimum
Cesium gap	0.254 mm; T_R = 380 to 540 K
Additive	Th and O
Geometry	cylindric; 20.3 cm long, 74.7 cm^2
Output	7.1 W/cm^2 with 11.5 percent efficiency out of core at T_E = 1940 K, T_R = 531 K
Lifetime	removed after 1100 hr

120. Henne, R.: Thermionic Energy Conversion with a Ba-Cs-Diode, pp. 212-219.

Emitter	Mo; T_E = 1870 to 2000 K
Collector	Mo; T_C = 950° to 1150° C
Cesium gap	0.05 to 2.0 mm; T_R = 120° to 300° C

Additive Ba; T_{Ba} = 450 to 950 K
Geometry plane, guarded
Output maximum indicated, 6 W/cm^2 at 1.0 V, 0.1 mm spacing, T_E = 2000 K, T_C = 1220 K, T_{Ba} = 950 K, T_R = 450 K

121. Wilson, V. C.: Output Performance of a Thermionic Converter with an Oriented Tungsten (110) Emitter and a Polycrystalline Tungsten Collector, pp. 220-224.

Emitter Cl^-TVD W(110) (thermally vapor-deposited); T_E = 1673, 1865, 2057 K
Collector polycrystalline W; Nb; Ni; T_C = 858 to 1073 K and optimum
Cesium gap 0.051 to 0.508 mm; T_R = 348 to 453 K and optimum
Geometry plane, guarded
Output good performance comparison; at 10 A/cm^2, T_C and T_R optimum the output was as follows:

Collector	T_E, K					
	1673		1865		2057	
	Volts	Ratio	Volts	Ratio	Volts	Ratio
Nb	0.39	1.00	0.73	1.00	1.03	1.00
W	.45	1.15	.78	1.07	1.12	1.09
Ni	.41	1.05	.85	1.16	1.22	1.18

122. Manista, E. J.; Smith, A. L.; and Lancashire, R. B.: Comparison of Computer-Acquired Performance Data from Several Fixed Space Planar Diodes, pp. 225-230.

Emitter etched Re; Cl^-CVD W (110); PVD W; T_E = 1500 to 2000 K
Collector Mo; Nb; T_C = 750 to 1100 K
Cesium gap 0.254 mm; T_R = 520 to 650 K
Geometry plane, guarded
Output voltages at 10 A/cm^2 with T_R and T_C optimum were as follows:

Diode	T_E, K			
	1700	1800	1900	2000
	Voltage, V			
Re, Nb	0.43	0.60	0.77	0.93
CVD-W, Nb	.35	.51	.60	.74
Re, Mo	.33	.43	.53	.66
PVD-W, Nb	.30	.36	.50	.66

123. Rufeh, F.; Gunther, B.; and Lieb, D.: Performance Comparison of Thermionic Converters with Several Collector Materials, pp. 231-240.

Emitter	Cl^-CVD W (110); T_E = 1600 to 2000 K
Collector	PVD Mo; Nb; W; single-crystal 110 W; T_C = 620 to 1020 K
Cesium gap	0.127 to 1.016 mm; T_R = 517 to 647 K
Additive	special care to minimize O_2 effects
Geometry	plane, guarded
Output	5.1 to 7.8 W/cm^2 with single-crystal-110-W collector and approximately 3.9 to 6.2 W/cm^2 with each of the other collectors, all for 0.254 mm spacing, 10 A/cm^2, T_E = 1700 to 1900 K; excellent performance maps

124. Dunlay, J.; Matsuda, S.; and Poirier, V.: Cylindrical Diode Characteristics with Sublimed Electrode Surfaces, pp. 242-247.

Emitter	PVD W (compared with Cl^-CVD W and F^-CVD W); T_E = 1600 to 1900 K
Collector	PVD Mo (with MoO_2 and MoO_3)
Cesium gap	0.508 mm; T_R = 250° to 300° C
Additive	O with PVD-Mo collector
Geometry	cylindric, cup-shaped; 37 cm^2
Output	outputs limited to 7 A/cm^2 by test facility; at 6 A/cm^2, 0.508 mm spacing, T_E = 1600 to 1900 K the output was as follows:

Diode	W/cm^2
PVD-W, PVD-Mo	2.3 to 6.2
Cl^-CVD-W, Nb	2.1 to 3.8
F^-CVD-W, Nb	0.6 to 2.1

125. Shimada, K.: Out-of-Core Evaluations of a Nonfueled and a UO_2-Fueled Cylindrical Thermionic Converter, pp. 248-252.

Emitter	etched Re (with and without UO_2 backing); T_E = 1700 to 2000 K
Collector	PVD Mo; T_C optimum (until heater failed)
Cesium gap	0.203 mm; T_R optimum
Additive	U and O (both definitely diffused through the emitter at 1900 to 2000 K)

Geometry	cylindric, 1.27-cm diameter, 15.2 cm^2
Output	6.5 W/cm^2 at 0.9 V with 11 percent efficiency for fueled diode, which was quite inferior to nonfueled one
Lifetime	during 2400 hr at 2000 K fueled diode lost 15 percent in output current; nonfueled one showed no change after 4000 hr

126. Shimada, K.; and Cassell, P. L.: Evaluations of Uranium-Nitride Fueled Converters, pp. 253-257.

Emitter	Re; W (each UN backed); T_E = 1660 to 2000 K
Collector	Nb; T_C = 806, 840 K, optimum
Cesium gap	0.25 mm; T_R = 555 to 622 K and optimum
Additive	U and N possible
Geometry	plane; 1.82 cm^2
Output	at 10 A/cm^2 the output was as follows:

Emitter	T_E, K	
	1800	2000
	W/cm^2	
Re	5.7	8.0
W	1.2	3.2

127. Haar, W.; and Holick, H.: Parametric Optimization of a Cylindrical Converter with a Molybdenum Emitter and Niobium Collector, pp. 258-263.

Emitter	Mo; T_E = 1550 to 2000 K
Collector	Nb, 1 percent Zr; T_C = 750 to 1020 K
Cesium gap	0.16 mm; T_R = 580 to 670 K
Geometry	cylindric; 2-cm diameter, 34 cm^2
Output	optimums from 1550 to 2000 K, 0.8 to 6.5 W/cm^2; 3.4 to 12 percent efficiencies

128. Rasor, N. S.; and Britt, E. J.: Suppression of Arc Drop in Thermionic Converters, pp. 272-281.

Emitter	CVD W; T_E = 1890 K
Collector	Mo
Cesium gap	0.013 to 0.508 mm; 4 torr
Geometry	plane
Output	performance characteristics of an Ar diode (mixed-oxide emitter, Cu collector) contribute to understanding Cs counterparts

129. McCandless, R. J.; and Wilkins, D. R.: Computed Performance Data for a Thermionic Converter Having a Cl-CVD-W Emitter and a Polycrystalline Nb Collector, pp. 282-287.

Emitter	Cl^-CVD W (110); T_E = 1600 to 2200 K
Collector	Nb; T_C = 800 to 1200 K
Cesium gap	0.254 to 0.381 mm; T_R = 540 to 653 K
Geometry	based on data from a plane, guarded diode
Output	SIMCON correlation of V. C. Wilson results; for 10 A/cm^2 and 0.254 mm spacing the output was as follows:

T_E, K	1651	1843	2035
T_C, K	948	998	1073
T_R, K	573	600	625
W/cm^2	4.0	7.0	9.5

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 16, 1972,
503-25.

NASA-Langley, 1972 —— 22 E-6989

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546